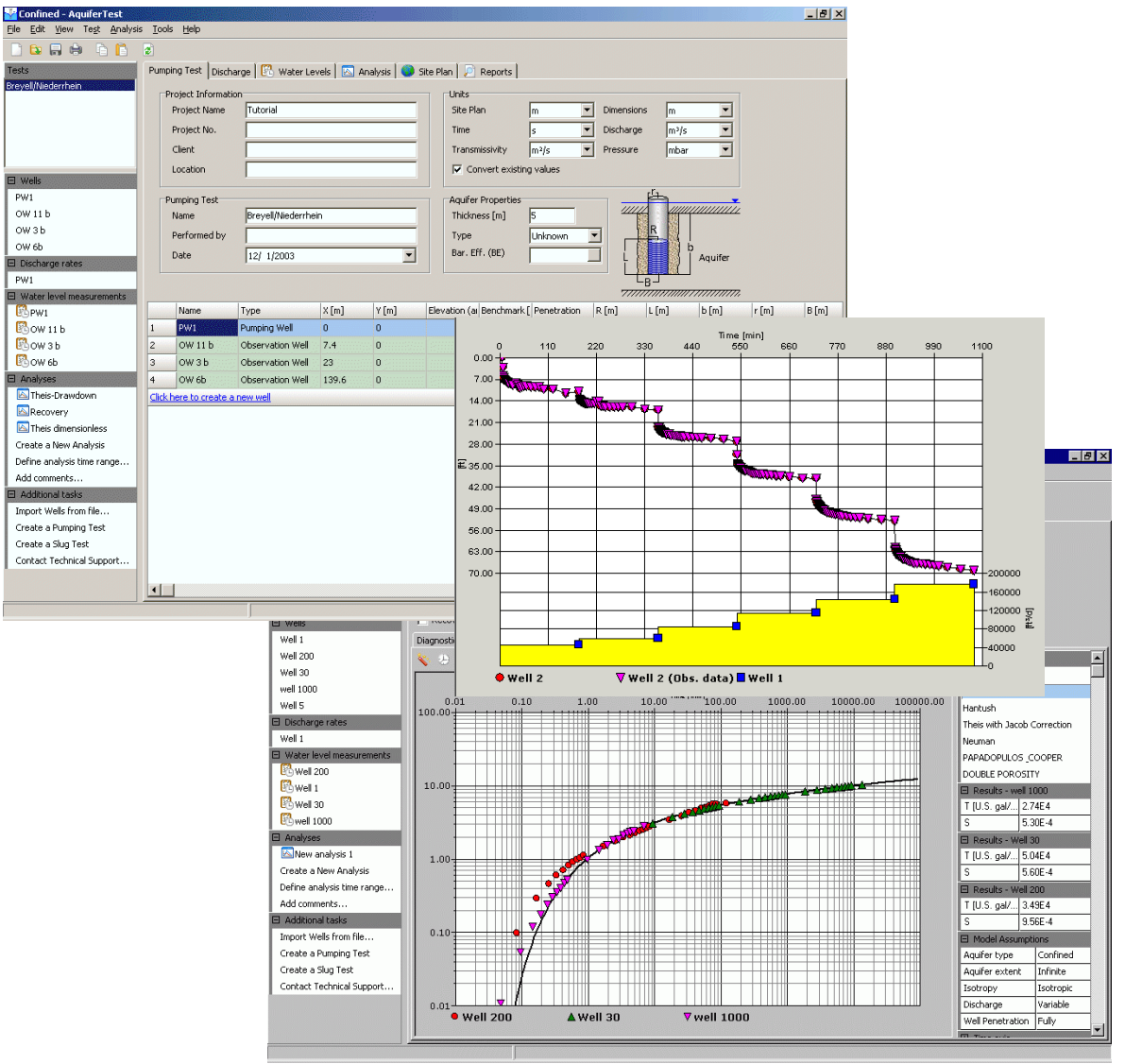
AquiferTest v.4.2
User's Manual

Advanced Pumping Test & Slug Test Analysis Software



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Preface

Schlumberger Water Services (SWS) is a recognized leader in the development and application of innovative groundwater technologies in addition to offering expert services and professional training to meet the advancing technological requirements of today's groundwater and environmental professionals.

Waterloo Hydrogeologic Software (WHS) consists of a complete suite of environmental software applications engineered for data management and analysis, modeling and simulation, visualization, and reporting. WHS is currently developed by SWS and sold globally as a suite of desktop solutions.

For over 18 years, our products and services have been used by firms, regulatory agencies, and educational institutions around the world. We develop each product to maximize productivity and minimize the complexities associated with groundwater and environmental projects. To date, we have over 14,000 registered software installations in more than 85 countries!

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To help us handle your technical support questions as quickly as possible, please have the following information ready before you call, or include it in a detailed technical support e-mail:

- A complete description of the problem including a summary of key strokes and program event (or a screen capture showing the error message, where applicable)
- Product name and version number
- Product serial number
- Computer make and model number
- Operating system and version number
- Total free RAM
- Number of free bytes on your hard disk

- Software installation directory
- Directory location for your current project files

You may send us your questions via e-mail, fax, or call one of our technical support specialists. Please allow up to two business days for a response. Technical support is available 8:00 am to 5:00 pm EST Monday to Friday (excluding Canadian holidays).

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Schlumberger Water Services offers numerous, high quality training courses globally. Our courses are designed to provide a rapid introduction to essential knowledge and skills, and create a basis for further professional development and real-world practice. Open enrollment courses are offered worldwide each year. For the current schedule of courses, visit: www.swstechnology.com/training or e-mail us at: sws-training@slb.com.

Schlumberger Water Services also offers expert consulting and peer reviewing services for data management, groundwater modeling, aqueous geochemical analysis, and pumping test analysis. For further information, please contact sws-services@slb.com.

Waterloo Hydrogeologic Software

We also develop and distribute a number of other useful software products for the groundwater professionals, all designed to increase your efficiency and enhance your technical capability, including:

- Visual MODFLOW Premium*
- HydroGeo Analyst*
- Aquifer Test Pro*
- AquaChem*
- GW Contour*
- UnSat Suite Plus*
- Visual HELP*
- Visual PEST-ASP
- Visual Groundwater*

Visual MODFLOW Premium

Visual MODFLOW Premium is a three-dimensional groundwater flow and contaminant transport modeling application that integrates MODFLOW-2000, SEAWAT-2000, MODPATH, MT3DMS,

MT3D99, RT3D, VMOD 3D-Explorer, WinPEST, Stream Routing Package, Zone Budget, MGO, SAMG, and PHT3D. Applications include well head capture zone delineation, pumping well optimization, aquifer storage and recovery, groundwater remediation design, simulating natural attenuation, and saltwater intrusion.

Hydro GeoAnalyst

HydroGeo Analyst is an information management system for managing groundwater and environmental data. HydroGeo Analyst combines numerous pre and post processing components into a single program. Components include, Project Wizard, Universal Data Transfer System, Template Manager, Materials Specification Editor, Query Builder, QA/QC Reporter, Map Manager, Cross Section Editor, HGA 3D-Explorer, Borehole Log Plotter, and Report Editor. The seamless integration of these tools provide the means for compiling and normalizing field data, analyzing and reporting subsurface data, mapping and assessing spatial information, and reporting site data.

AquiferTest Pro

AquiferTest Pro, designed for graphical analysis and reporting of pumping test and slug test data, offers the tools necessary to calculate an aquifer's hydraulic properties such as hydraulic conductivity, transmissivity, and storativity. AquiferTest Pro is versatile enough to consider confined aquifers, unconfined aquifers, leaky aquifers, and fractured rock aquifers conditions. Analysis results are displayed in report format, or may be exported into graphical formats for use in presentations. AquiferTest Pro also provides the tools for trends corrections, and graphical contouring water table drawdown around the pumping well.

AquaChem

AquaChem is designed for the management, analysis, and reporting of water quality data. AquaChem’s analysis capabilities cover a wide range of functions and calculations frequently used for analyzing, interpreting and comparing water quality data. AquaChem includes a comprehensive selection of commonly used plotting techniques to represent the chemical characteristics of aqueous geochemical and water quality data, as well includes PHREEQC - a powerful geochemical reaction model.

GW Contour

The GW Contour data interpolation and contouring program incorporates techniques for mapping velocity vectors and particle tracks. GW Contour incorporates the most commonly used 2D data interpolation techniques for the groundwater and environmental industry including Natural Neighbor, Inverse Distance, Kriging, and Bilinear. GW Contour is designed for contouring surface or water levels, contaminant concentrations, or other spatial data.

UnSat Suite Plus

UnSat Suite Plus seamlessly integrates multiple one-dimensional unsaturated zone flow and solute transport models into a single, intuitive working environment. Models include SESOIL, VS2DT, VLEACH, PESTAN, Visual HELP and the International Weather Generator. The combination of models offers users the ability for simulating the downward vertical flow of water and the migration of dissolved contaminants through the vadose zone. UnSat Suite Plus includes tools for project management, generating synthetic weather data, modeling flow and contaminants through the unsaturated zone, estimating groundwater recharge and contaminant loading rates, and preparing compliance reports.

Visual HELP

Visual HELP is a one-dimensional, unsaturated zone flow modeling application built for optimizing the hydrologic design of municipal landfills. Visual HELP is based on the US E.P.A . HELP model (Hydrologic Evaluation of Landfill Performance) and has been integrated into a 32-Bit Windows application. It combines the International Weather Generator, Landfill Profile Designer, and Report Editor. Applications include designing landfill profiles, predicting leachate mounding, and evaluating potential leachate seepage to the groundwater.

Visual PEST-ASP

Visual PEST-ASP combines the powerful parameter estimation capabilities of PEST-ASP, with the graphical processing and display features of WinPEST. Visual PEST-ASP can be used to assist in data interpretation, model calibration and predictive analysis by optimizing model parameters to fit a set of observations. This popular estimation package achieves model independence through its capacity to communicate with a model through its input and output files.

Visual Groundwater

Visual Groundwater is a visualization software package that delivers high-quality, three-dimensional representations of subsurface characterization data and groundwater modeling results. Combining graphical tools for three-dimensional visualization and animation, Visual Groundwater also features a data management system specifically designed for borehole investigation data. The graphical display features allow the user to display site maps, discrete data contours, isosurfaces and cross sectional views of the data.

Groundwater Instrumentation

Diver-NETZ

Diver-NETZ is an all-inclusive groundwater monitoring network system that integrates high-quality field instrumentation with the industries latest communications and data management technologies. All of the Diver-NETZ components are designed to optimize your project workflow from collecting and recording groundwater data in the field - to project delivery in the office.

*Mark of Schlumberger

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1

Introduction

Congratulations on your purchase of **AquiferTest**, the most popular software package available for graphical analysis and reporting of pumping test and slug test data!

AquiferTest is designed by hydrogeologists for hydrogeologists giving you all the tools you need to efficiently manage hydraulic testing results and provide a selection of the most commonly used solution methods for data analysis - all in the familiar and easy-to-use Microsoft Windows environment.

AquiferTest has the following key features and enhancements:

- Runs as a native Windows 32-bit application
- Easy-to-use, intuitive interface
- Solution methods for unconfined, confined, leaky confined and fractured rock aquifers
- Derivative drawdown plots
- Professional style report templates
- Easily create and compare multiple analysis methods for the same data set
- Step test/well loss methods
- Single well solutions
- Universal Data Logger Import utility (supports a wide variety of column delimiters and file layouts).
- Support for Level Loggers and Diver Dataloggers
- Import well locations and geometry from an ASCII file
- Import water level data from text or Excel format
- Windows clipboard support for cutting and pasting of data into grids, and output graphics directly into your project report
- Site map support for .dxf files and bitmap (.bmp) images
- Contouring of drawdown data
- Dockable, customizable tool bar and navigation panels
- Numerous short-cut keys to speed program navigation

AquiferTest provides a flexible, user-friendly environment that will allow you to become more efficient in your aquifer testing projects. Data can be directly entered in **AquiferTest** via the keyboard, imported from a Microsoft Excel workbook file, or imported from any data logger file (in ASCII format). Test data can also be inserted

from a Windows text editor, spreadsheet, or database by “cutting and pasting” through the clipboard.

Automatic type curve fitting to a data set can be performed for standard graphical solution methods in **AquiferTest**. However, you are encouraged to use your professional judgement to validate the graphical match based on your knowledge of the geologic and hydrogeologic setting of the test. To easily refine the curve fit, you can manually fit the data to a type curve using the parameter controls.

With **AquiferTest**, you can analyze two types of test results:

[1] Pumping tests, where water is pumped from a well and the change in water level is measured inside one or more observation wells (or, in some cases, inside the pumping well itself). You can present data in three different forms:

- Time versus water level
- Time versus discharge (applicable for variable rate pumping tests)
- Discharge versus water level (applicable for well performance analysis)

The following pumping test analysis methods are available, with fixed analysis assumptions:

- Cooper-Jacob Time Drawdown
- Cooper-Jacob Distance-Drawdown
- Cooper-Jacob Time-Distance-Drawdown
- Theis Recovery

With these analysis methods, it is not possible to modify the model assumptions. For more details, please see see “Pumping Test Methods - Fixed Assumptions” on page 145

The following pumping test analysis methods allow adjusting the model assumptions for customized analysis:

- Theis (1935)
- Hantush-Jacob (Walton) (1955)
- Neuman (1975)
- Theis with Jacob Correction
- Warren Root Double Porosity (Fracture Flow)
- Papadopulos - Cooper (1967)
- Agarwal Recovery
- Moench Fracture Flow (1984)
- Hantush with storage (1960)

With these analysis methods, it is possible to adjust the model assumptions to match the pumping test conditions. For more details, please see see “Pumping Test Methods” on page 152.

Finally, the following test is available for analyzing well performance

- Specific Capacity Test

- Hantush-Bierschenk Well Losses

[2] Slug (or bail) tests, where a slug is inserted into a well (or removed from a well) and the change in water level in the side well is measured. You can have data in one form:

- Time versus water level

The following slug test analysis methods are available:

- Hvorslev (1951)
- Bouwer-Rice (1976)
- Cooper-Bredehoeft-Papadopulos (1967)

The exercises in Chapter 7: Demonstration Exercises and Benchmark Tests, will introduce you to many features of **AquiferTest**.

1.1 What's New in AquiferTest

The main interface for AquiferTest has much of the same user-friendly look and feel as the previous version, but with some significant improvements to analysis. Some of the more significant upgrade features in the latest versions of AquiferTest are described below.

1.1.1 New Features in Version 4.2

The following new features are available in Version 4.2

Analysis Methods

- Added Hantush-Bierschenk (1964) - step drawdown test, analysis of well loses. Two data analysis options:
  - Analyze discharge-water level data (for a step test, where steady-state is reached in each step)
  - Manually enter the time-discharge data and time-water level data, and extrapolate discharge-water levels from this data (appropriate for a step test, where flow is at an unsteady-state).
- Added Moench Fracture Flow (1984) - analysis of fractured aquifers with a fractured skin.
  - Select from Transient or Pseudo-steady state block to fissure flow model
  - Select sphere or slab block geometry.
- Added Hantush (1960) - Leaky aquifer, unsteady-state flow, accounts for storage changes in the aquitard

Mapping

- Export drawdown contours to polyline shapefile (geometry and attributes)
- Export well locations to points shapefile (geometry and attributes)
- Import well locations from point shapefile (geometry and attributes)

Reports

- Added 4 user-defined report fields, with user-defined label name, text value and style settings.

1.1.2 New Features in Version 4.1

The following new features are available in Version 4.1

Analysis Methods

- Added Theis Recovery analysis
- Added Cooper Jacob analysis
  - Time-Drawdown
  - Distance-Drawdown
  - Time-Distance Drawdown
  - Option show the Cooper Jacob validity line, and define different values for "u"
- Added Boulton method; this analysis method is suitable for unconfined aquifers, anisotropic or isotropic, with fully or partially penetrating wells. This is an optional substitute for the Neuman analysis
- Added option to display Statistics for the Automatic fit, under the Analysis menu. The statistics report may be saved to file .TXT or .XLS, or copied to a clipboard, or printed as is

Maps and Contouring

- Export contour lines, modified the grid export routine, in order to have real-world x,y,z coordinates
- Added features to export to graphics format (.BMP) and copy to clipboard

Data Import

- Added support for .MON Diver Datalogger format

Units

- Added imperial gallons /min or /day also be included as a unit option for discharge rate

1.1.3 New Features in Version 4.0

The following new features are available in Version 4.0.

Program Design

- The GUI in **AquiferTest** is easier to navigate and use. The data entry and analysis are separated into 5 or 6 simple pages (tabs) depending on the type of test used
- Windows XP browser panels can be used for short-cuts, or hidden from the view
- Single file format (SDI application). Files are smaller in size, and more manageable. There is one program window for each file/document. As such, it

is possible to open several instances of the program and working on several files (projects) at the same time.

Analysis Features

- Analysis Plots: Choose from Drawdown plot or Type Curve (dimensionless) on the fly
- Diagnostic Plots: compare observed data or drawdown derivative data to standard curves in log-log or semi-log scales, to help determine aquifer type, and diagnose the presence of well effects, boundary effects, leaky aquifer, etc. before running the analysis.
- Automatically or manually fit a data set to type curves. Manually adjust parameters for any analysis type, making any solution forward-predictive.

Analysis Methods

AquiferTest supports pumping test solutions for the following conditions:

- Confined Aquifers
- Unconfined Aquifers
- Leaky Aquifers
- Fracture Flow (Dual Porosity) Aquifers
- Fully and partially penetrating Pumping wells and/or Observations wells or Piezometers
- Infinite extent of Aquifer or bounded by recharge or barrier boundary
- Isotropic or Anisotropic Aquifer
- Constant or Variable discharge rates
- Single or Multiple pumping wells
- Well losses and well storage
- Agarwal Recovery analysis

For Slug tests, the following aquifer types are supported:

- Confined Aquifers
- Unconfined Aquifers
- Leaky Aquifers
- Fully and partially penetrating test wells
- Large diameter well analysis (accounting for storage in the well)

Graphs

- More flexibility for graph settings (specify interval, max, min, log scale, grid lines, etc.).
- Save custom graph settings, and set as defaults
- Floating parameters dialog for adjusting T, S, and K values for multiple wells
- Display calculated parameter values for all wells simultaneously

- Fit multiple wells to one type curve, simultaneously
- Display multiple drawdown or type curves simultaneously
- Use standard type curve, or derivative type curve for curve fitting and parameter calculation

Site Maps

- Load and georeference a raster image or .DXF file containing a site plan.
- *Display contour lines or a color-shaded map of drawdown data, with an option for a site map in the background. For more information see Chapter 6: Mapping and Contouring.

NOTE: *Contouring and color shading available in AquiferTest Pro only.

Data Import and Management

- Import data from Excel, Text, .ASCII.
- Import data logger files, with pre-defined import settings for Level Loggers and Diver Dataloggers
- Save data logger import settings for future use
- Import wells from text or excel files
- Data filter to reduce number of data points and improve calculation speed (it is now possible to filter a data set AFTER it has have been imported)
- Filter option to keep data points where the discharge rate changes, to ensure that critical data points are not lost.
- Import data from **AquiferTest v.3.X** database

Data Preprocessing Options

AquiferTest complies with the U.S. EPA Protocol: "U.S. EPA-SOP for Aquifer Pumping Tests" (EPA/540/S-93/503), which requires pumping test data to be corrected for barometric effects, and/or local/regional water level trends. There are three data pre-processing options now available:

- Data Trend Correction - determine if the water level trend affected pumping test results. Run a t-test analysis on data set, to determine if trend is significant or not. The drawdown can then be corrected according to the trends, and the corrected drawdown data may be used for the calculation of the aquifer parameters.
- Barometric Correction - Using the Barometric Efficiency (BE) of the aquifer, determine if barometric influence was significant or not using a t-test analysis. The drawdown can then be corrected according to the barometric effects, and the corrected drawdown data may be used for the calculation of the aquifer parameters.

- Create and save a custom data trend correction and apply it to a single well, or all wells (for example, create a trend correction to account for the influence of tidal effects during the pumping test)

NOTE: Data pre-processing options available in AquiferTest Pro only.

User Settings

- Save units as defaults for all new projects
- Easily change units and convert values on the fly.
- Display Transmissivity in units of US Gal / day-ft

Reports and Printing

- Customize company name, logo, and header info.
- Several standard pre-defined reports including:
  - Site Map
  - Wells
  - Time vs. Drawdown Data
  - Trend Correction Analysis
  - Barometric Correction Analysis
  - Analysis Plot
  - Analysis Summary Results table
- It is now possible to print all reports at once, from one window, instead of having to load data reports individually.

For more information on **AquiferTest** or to order an upgrade, please contact us at:

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1.2 Installing AquiferTest

1.2.1 System Requirements

To run **AquiferTest** you need the following minimum system configuration:

- A CD-ROM drive for software installation
- A hard drive, with at least 35 MB free
- A local or network printer installed

- A Pentium processor, 300 MHz or better, with 128 MB RAM
- Windows 2000 Pro SP4 or Windows XP Pro, SP2, Windows Vista Business, Enterprise or Ultimate. Note: Currently, Windows Vista Home Basic, Home Premium and Starter versions are not supported.
- MSExcel (any version) installed
- A Microsoft or compatible mouse
- Minimum 600 x 800 screen resolution (1024 x 768 recommended)
- Recommended internet connection

1.2.2 Installation

AquiferTest is distributed on one CD-ROM.

Place the CD into your CD-ROM drive and the initial installation screen should load automatically. Once loaded, an installation interface with several different tabs will be presented.

Please take the time to explore the installation interface, as there is information concerning other Schlumberger Water Services products, our worldwide distributors, technical support, consulting, training, and how to contact us.

On the initial Installation tab, you may choose from the following two buttons:

- **AquiferTest** User's Manual
- **AquiferTest** Installation

The User's Manual button will display a PDF document of the manual, which requires the Adobe Reader to view. If you do not have the Adobe Reader, a link has been created in the interface to download the appropriate software.

The Installation button will initiate the installation of the software on your computer. **AquiferTest** must be installed on your hard disk in order to run. If you are using Windows XP or 2000, ensure that you have administrative rights for the installation and software registration.

Please follow the installation instructions, and read the on-screen directions carefully.

After the installation is complete you should see the **AquiferTest** icon on your Desktop screen, labeled as such and/or have a link in your **Programs** menu to SWS Software and consequently to **AquiferTest**. To start working with **AquiferTest**, double-click this icon or navigate to the link described above.

NOTE: To install the software from the CD-ROM without the aid of the installation interface, you can:

- Open Windows Explorer, and navigate to the CD-ROM drive
- Open the Installation folder
- Double-click on the installation file to initiate the installation

Follow the on-screen installation instructions, which will lead you through the install and subsequently produce a desktop icon for you.

1.3 Updating Old Projects

AquiferTest is backwards compatible, and is able to open any projects from v.4.x and v.3.x. It is recommended that you ALWAYS create a backup copy of any project files before you open them in the new version. Specifically, ensure that you back up your original MS Access database (.MDB), which contains all project data.

* Schlumberger Water Services is not responsible for any direct or indirect damages caused to projects during conversion. It is strongly recommended that you create a secure, independent back up of projects before converting.

1.4 Learning AquiferTest

1.4.1 Online Help

This User's Manual is supplied to you in two forms: as a printed book, and as an on-line help file. To view the electronic help version of this manual, select **Help**, then **Contents**.

1.4.2 Sample Exercises and Tutorials

There are several sample projects included with **AquiferTest**, which demonstrate the numerous features, and allow you to navigate and learn the program. Feel free to peruse through these samples.

To begin working with your own data, please skip to Chapter 2: Getting Started, for a step-by-step summary of how to create a pumping test, and how to create a slug test.

1.4.3 Suggested Reference Material

Additional information can be obtained from hydrogeology texts such as:

- Freeze, R.A. and J.A. Cherry, 1979. Groundwater, Prentice-Hall, Inc. Englewood Cliffs, New Jersey 07632, 604 p.
- Kruseman, G.P. and N.A. de Ridder, 1990. Analysis and Evaluation of Pumping Test Data Second Edition (Completely Revised) ILRI publication 47. Intern. Inst. for Land Reclamation and Improvements, Wageningen, Netherlands, 377 p.
- Fetter, C.W., 1994. Applied Hydrogeology, Third Edition, Prentice-Hall, Inc., Upper Saddle River, New Jersey, 691 p.

- Dominico, P.A. and F.W. Schwartz, 1990. Physical and Chemical Hydrogeology. John Wiley & Sons, Inc. 824 p.
- Driscoll, F. G., 1987. Groundwater and Wells, Johnson Division, St. Paul, Minnesota 55112, 1089 p.

In addition, several key publications are cited at the end of Chapter 4.

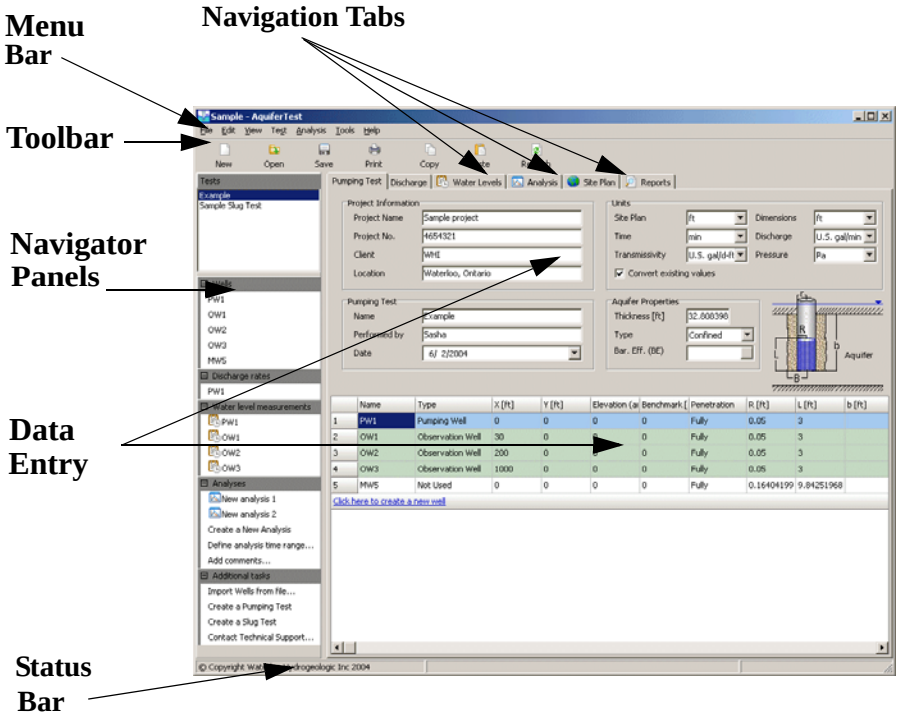
1.5 About the Interface

AquiferTest is designed to automate the most common tasks that hydrogeologists and other water supply professionals typically encounter when planning and analyzing the results of an aquifer test. The program design allows you to efficiently manage all information from your aquifer test and perform more analyses in less time. For example, you need to enter information about your testing wells (e.g. X and Y coordinates, elevation, screen length, etc.) only once in **AquiferTest**. After you create a well, you can see it in the navigator panel, or in the wells grid.

When you import data or create an analysis, you specify which wells to include from the list of available wells in the project. If you decide to perform additional analyses, you can again specify from the available wells without re-creating them in **AquiferTest**. There is no need to re-enter your data or create a new project. Your analysis graph is refreshed, and the data re-analyzed using the selected solution method. This is useful for quickly comparing the results of data analysis using different solution methods. If you need solution-specific information for the new analysis, **AquiferTest** prompts you for the required data.

1.5.1 Getting Around

A typical **AquiferTest** window is shown below followed by descriptions of the different sections.



The **AquiferTest** Interface is composed of several components:

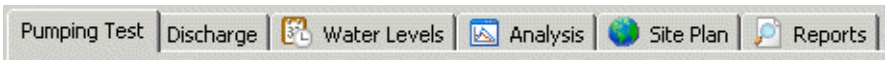
- **Navigation Tabs:** Provide access to the data entry and analysis windows in the program; these include Pumping/Slug Test, Discharge, Water Levels, Analysis, Site Plan, and Reports.
- **Menu Bar:** Contains menu commands with access to all the functions available in the **AquiferTest**.
- **Toolbar:** Contains several context sensitive short-cut buttons for some of the frequently used **AquiferTest** tools.
- **Navigation Panel:** Contains a tree view of all of the components which comprise an **AquiferTest** project. These include panels for Tests, Wells, Discharge Rates, Water Level data, Analyses, and other frequently used tasks.
- **Data Entry:** Contains the fields and grids for data entry and visualization.
- **Status Bar:** Displays the program status.

The following sections describe each of these components in greater detail.

1.5.2 Navigation Tabs

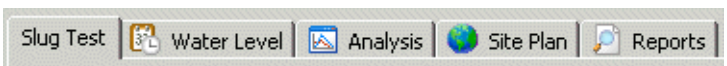
The interface in **AquiferTest** has been designed so that information can be quickly and easily entered, and modified later if needed. The data entry and analysis windows have been separated into navigation tabs; the tabs are logically ordered such that the information flow is in a left-to-right fashion; this means that data is first entered in the far left tab, then the process proceeds to the right from there. The tabs are explained below:

For pumping tests:



- **Pumping Test** - project particulars, aquifer properties, pumping test details and info, well locations and dimensions and units
- **Discharge** - specify constant or variable discharge rates for one or more pumping wells
- **Water Levels** - time drawdown data, filtering, and trend affects
- **Analysis** - contains selected analysis graphs and associated options (diagnostic plots, drawdown derivatives) and calculated parameters
- **Site Plan** - map showing basemaps, well locations and optional contouring of drawdown.
- **Reports** - preview and print selected reports

For slug tests:



- **Slug Test** - project particulars, aquifer properties, slug test details and info, well locations and dimensions, and units
- **Water Levels** - water level data
- **Analysis** - analysis graphs and calculated parameters
- **Site Plan** - map showing basemaps and well locations
- **Reports** - preview and print selected reports

Pumping Test Tab

The pumping test tab contains all the general information pertaining to the site where the tests were conducted. This information need only be entered once and is displayed in the panel unchanged for any additional tests that are created.

Units are specified for the currently active pumping test. When a new pumping test is created, the units return to default and must be changed accordingly. The default units can be set by selecting **Tools / Options / General**. The units for **Site Plan** control the

XY coordinates and the elevation data; the **Dimensions** units control the well geometry (r, L, etc.) and water levels; the **Time**, **Discharge**, and **Pressure** units control their respective parameters; **Transmissivity** units control the units for the calculated parameters transmissivity, storativity, and conductivity.

Pumping test details can be entered for each new test. Different descriptive names for the tests allow for easy navigation using the Project Navigator panel.

Aquifer properties can be specified for each pumping test. These include the aquifer thickness and the aquifer barometric efficiency (BE); the BE value is only necessary if you intend to correct the measured drawdown data based on barometric influences. The BE value may be directly entered in the field, or may be calculated from observed time-pressure data. For more details, see Chapter 5: Data Pre-Processing.

In addition, well names, coordinates, elevations, and geometry is entered in this window. XY coordinates are required, as they are used to calculate the radial distance to the pumping well. Well geometry values (r, R, L, b) are necessary only for certain solution methods.

If the option “use r(w)” is selected, then values for n (gravel pack porosity) must be defined.

All wells are available for the entire project, i.e. within the file for several pumping/slug tests. However, the **Type** attribute refers only to the current pumping/slug test.

Slug Test Tab

The slug test panel contains the same fields for the project, units, test, aquifer, wells, and site information as does the pumping test panel.

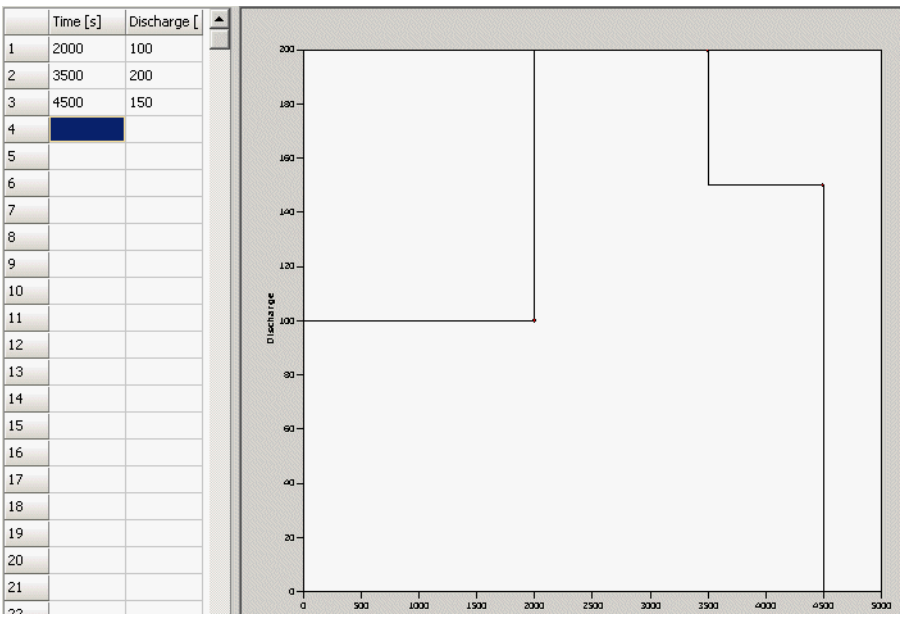
Discharge Tab (Pumping Test only)

This panel allows the user to specify the discharge rates for each pumping well. Discharge rates may be constant or variable. For variable pumping rates, the measured rates are entered into the table, and are plotted automatically on the corresponding graph window on the right. **AquiferTest** interprets the numerical data as the end of the respective pumping stage. Therefore, there is no need to enter a pumping rate at time 0; simply enter the rate at the end of the interval.

For example:

Time (s)	**Discharge (GPM)**
2000	**100**
3500	**200**
4500	**150**

The above inputs correspond to a first pumping stage from 0 to 2000 s with 100 gpm, Pumping stage 2 from 2000 s to 3500 s with 200 gpm, and pumping stage 3 from 3500 to 4500 s with 150 gpm.



Water Levels Tab

This panel contains fields for observation well data entry and provides graphical representation of this data. Data may be copied and pasted, imported using the Data Logger Wizard, or imported from a text or Excel file. When importing from Excel, only the first table sheet is imported and the data must be in the first two columns - Time in the first and Water Levels in the second.

In addition, there are data filtering options, and data corrections (trend affects, barometric affects, etc.) By reducing the number of measured values, you can improve the program performance, and calculate the aquifer parameters quicker.

Analysis Tab

The analysis panel contains the forum for calculating the aquifer parameters using the abundance of graphical solution methods. There are two main tabs available: **Diagnostic** and **Analysis**.

Diagnostic graphs

The **Diagnostic** graph provides tools for interpreting the drawdown data, and is a visual aid for determining the aquifer type if this is not well understood. The measured drawdown data are plotted on a log-log scale, or a semi-log scale.

On the right side, apart from the actual graph, the processes characteristic of different aquifer types are schematically represented. By comparing the observed data to the pre-

defined templates, it is possible to identify the aquifer type and conditions (confined, well bore storage, boundary influences, etc.) Using this knowledge, an appropriate solution method and assumptions can then be selected from the Analysis tab, and the aquifer parameters calculated.

In addition, **AquiferTest** calculates and displays the derivative of the measured drawdown values; this is helpful since quite often it is much easier to analyze and interpret the derivative of the drawdown data, then just the measured drawdown data itself.

Analysis graph tab

In the **Analysis** tab, there are several panels on the right hand side of the graph that allow setting up the graph, changing the aquifer parameters to achieve an optimal curve fit, model assumptions, display and other settings.

For more information, please see Chapter 3 - “Analysis Tab” on page 67.

Site Plan Tab

AquiferTest automatically plots the wells on a map layout. The site map layout may contain a CAD file or raster image (e.g. a topographic map, an air or satellite photograph etc.). Raster images must be georeferenced using two known co-ordinates, at the corners of the image. For more details, see “Import Map Image...” on page 88.

Reports Tab

The Reports page displays report previews, and allows the user to select from various report templates. The reports are listed in hierarchical order for the current pumping/ slug test. A zoom feature is available, with preview settings.

The dark grey area around the page displays the margins for the current printer. You can modify these settings by selecting **File/Printer Setup**.

Select **Print** on this page to print all selected reports. Using **Print** on a selected tab will print the context related report directly - such as a data report from the **Water Levels** page.

1.5.3 Menu Bar

The menu bar provides access to most of the features available in **AquiferTest**. For more details, see Chapter 3 - “Main Menu Bar” on page 86.

1.5.4 AquiferTest Toolbar

The following sections describe each of the items on the toolbar, and the equivalent icons. For a short description of an icon, move the mouse pointer over the icon *without* clicking either mouse button.

The toolbars that appear beneath the menu bar are dynamic, changing as you move from one window to another. Some toolbar buttons become available only when certain windows are in view, or in a certain context. For example, the **Paste** button is only available after the **Copy** command has been used.

The following tool buttons appear at the top of the **AquiferTest** main window:

New button creates a new project.

Open button opens an existing project.

Save button saves the current project.

Print button prints the data item which is currently getting the focus.

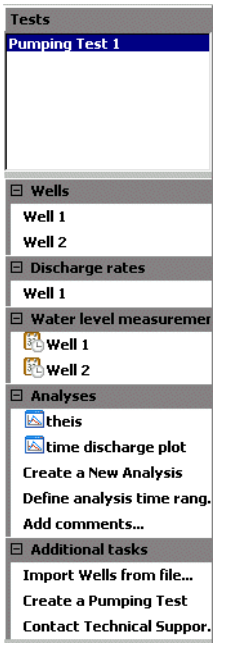
Copy button copies selected character(s) in a grid cell or a plot to the clipboard.

Paste button pastes text from the clipboard to the active cell.

Refresh button refreshes the current view.

1.5.5 Project Navigator Panels

The **Project Navigator** panel shows the tests, wells, and analyses for the current project, along with additional tasks. The panel is styled in a XP fashion. As with other Windows applications, you can use the + or - icon to expand or collapse a frame in the panel. In addition, you can show/hide the panel completely, using the **View / Navigation Panel** option.



Creating and deleting elements contained within the panel, including wells, data lists, pumping tests, slug tests, and associated analyses is discussed in Chapter 2: Getting Started and Chapter 3: General Info and Main Menu Bar.

Please do not confuse the **Project Navigator** panel and **Analysis Navigator** panel. The **Project Navigator** panel is located on the left of the program window and is always visible (unless you hide it in the **View** menu). The **Analysis Navigator** panel is located on the right of the main program window and is only visible in the **Analysis** tab.

2

Getting Started

This chapter is designed to serve as a ‘quick start’ reference guide, and is divided into sections for your convenience - feel free to read through the entire chapter or jump directly to a section of interest.

[1] 2.1 - Creating a Pumping Test

- 2.1.1 - Pumping Test Information
- 2.1.2 - Discharge Rates
- 2.1.3 - Water Level Data
- 2.1.4 - Creating a Pumping Test Analysis
- 2.1.5 - Reports

[2] 2.2 - Creating a Slug Test

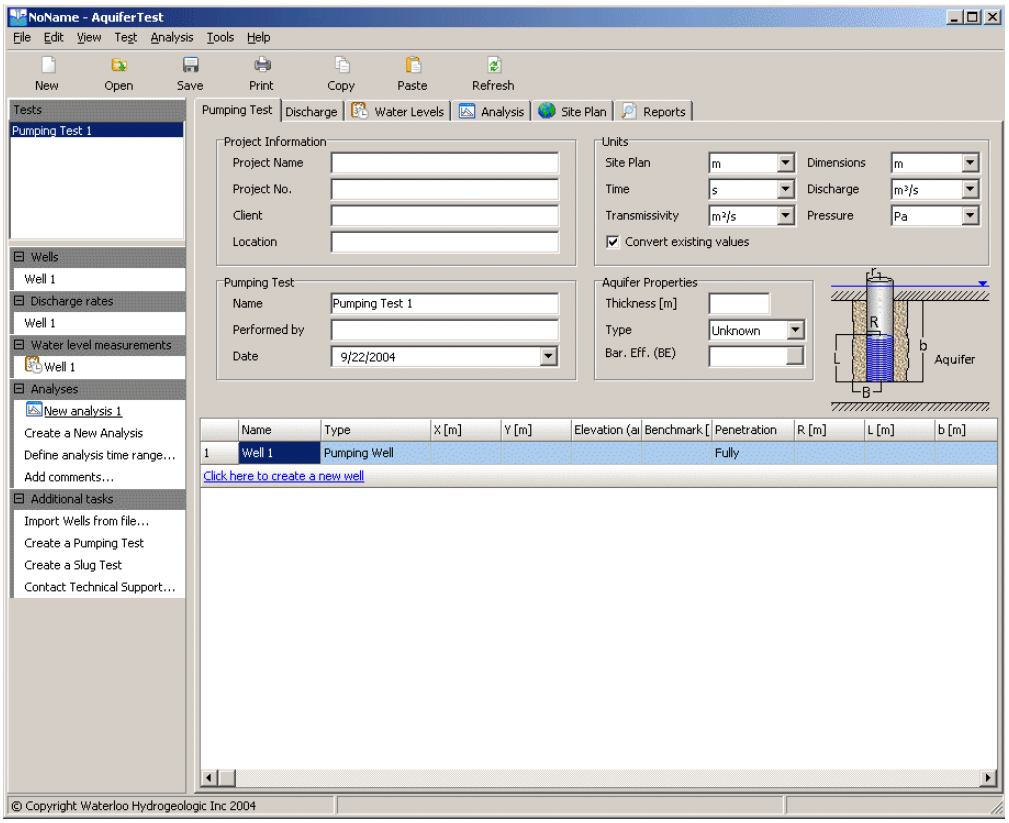
- 2.2.1 - Slug Test Information
- 2.2.2 - Water Level Data
- 2.2.3 - Creating a Slug Test Analysis
- 2.2.4 - Reports

2.1 Creating a Pumping Test

The dataset for this example was taken from Dawson and Istok, pg. 96.

To start **AquiferTest** navigate to **Programs/SWS Software/AquiferTest 4.2/ AquiferTest 4.2**, or double-click on the desktop icon .

Once **AquiferTest** is loaded, there will be an empty project file loaded by default, as shown below.



The first page (tab) is **Pumping Test**. In this window, define the project specifics, test details, units, aquifer dimensions, and wells.

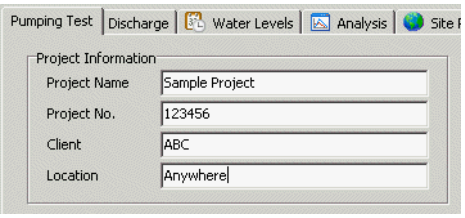
2.1.1 Pumping Test Information

Enter the following information in the **Pumping Test** tab:

Project Information

General details of the project:

- **Project Name:** Sample Project
- **Project No.:** any number
- **Client:** ABC
- **Location:** Anywhere

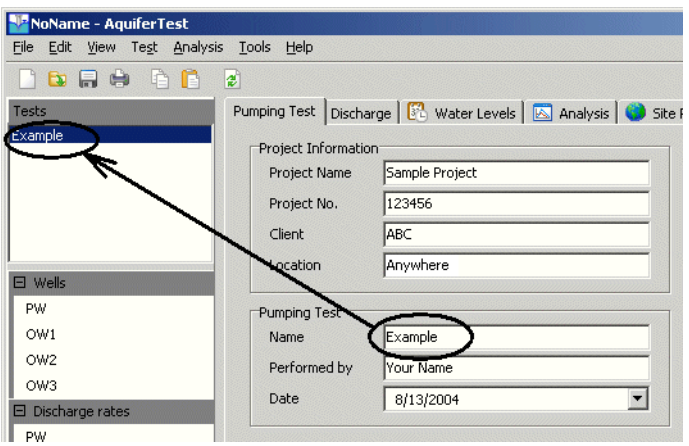


Pumping Test

General details for the selected pumping test:

- **Name:** Example
- **Performed by:** Your Name
- **Date:** Test Date

Once you have done this you should see **Example** in the **Tests** frame of the Navigator Panel (you may need to click the highlighted test under the **Tests** frame of the **Navigator Panel** to see the new information):



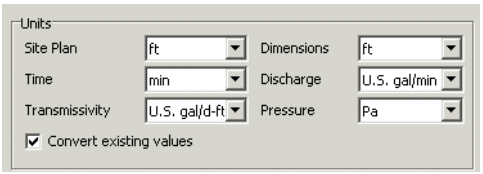
The Tests panel will allow you to switch between various pumping and slug tests in the project.

Units

This section will address the issue of units for the project. There are 6 combo boxes in the **Units** frame - click on the units list for **Site Plan**. There is a variety of metric and imperial units to choose from - simply select the appropriate unit.

Define the following units for this sample project:

Site Plan:	**ft**
Dimensions:	**ft**
Time:	**min**
Discharge:	**US gal/min**
Transmissivity:	**US gal/day-ft**
Pressure:	**Pa**



The **Convert existing values** checkbox allows you to convert the values to the new units without having to calculate and re-enter them manually.

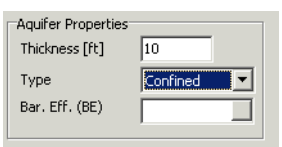
On the other hand, if you created a test with incorrect unit labels, you can switch the labels by de-selecting the **Convert existing values** option. That way, the physical labels will change but the numerical values will remain the same.

NOTE: The default units for new tests can be defined in the **Tools/Options/General** window.

Aquifer Properties

Enter the following parameters of the investigated aquifer:

Aquifer Properties	
Thickness (ft):	10
Type	confined
Bar.Eff.	leave blank



Well Locations and Geometry

Defining well locations and geometry can be accomplished either by entering each well and associated geometry one-by-one (manually), or by importing the data from a text file (.txt or .asc). For this example, you will manually enter and define the properties for 1 pumping well and 3 observation wells.

To enter a well manually, locate the **Wells** table at the bottom half of the window. By default, one pumping well will already have been defined for the new project.

Enter the following information for this well.

Name	**PW1**
Type	**Pumping Well***
X-coordinate:	**0**
Y-coordinate:	**0**
Elevation (amsl):	**0**
Benchmark:	**0**
Penetration	**Fully**
R (effective radius):	**0.05**
L (screen length):	**3**
b (dist from bottom of well screen to top of aquifer):	**leave blank**
r (casing radius):	**0.025**

*To change the well type click on the "**Type**" field twice (not double-click) and select from the drop-down menu.

The remaining fields can be left blank.

NOTE: The 'Pumping well b' value is the distance from the bottom of the pumping well screen to the top of the aquifer at the start time of the pumping test. In this example 'b' is not required, however this value is required to complete an analysis for partially penetrating wells.

Next, you must create an observation well. To do so,

Click "**Click here to create a new well**" located directly below the first row in the Wells table.

Enter the following information for this well:

Name	**OW1**
Type	**Observation Well**
X-coordinate:	**30**
Y-coordinate:	**0**
Elevation (amsl):	**0**
Benchmark:	**0**
Penetration	**Fully**
R (effective radius):	**0.05**
L (screen length):	**3**
b (dist from bottom of well screen to top of aquifer):	**leave blank**
r (casing radius):	**0.025**

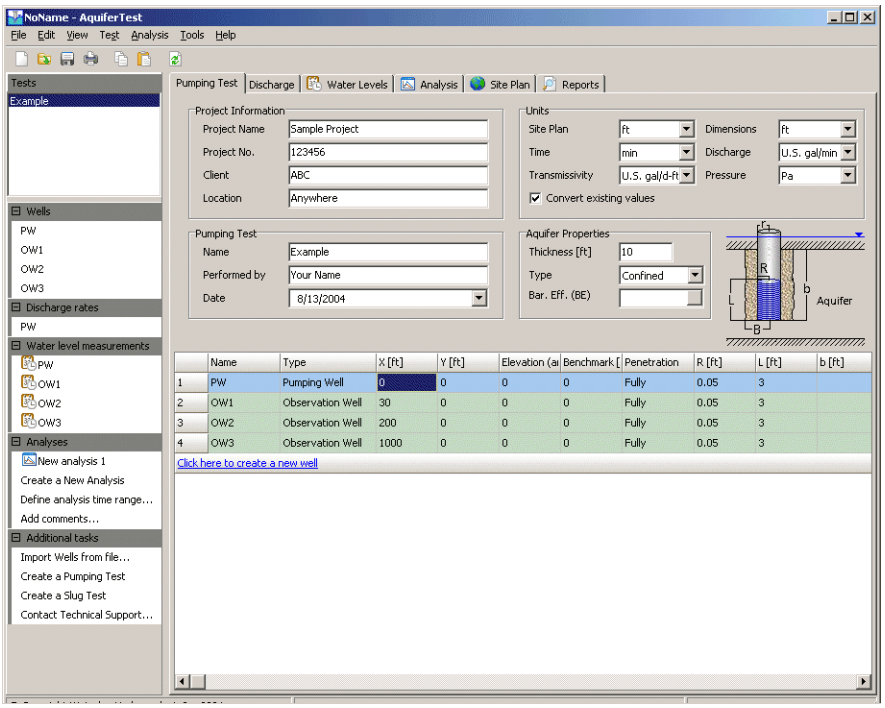
Using the same procedure add two additional observation wells and define the details as listed below:

Name	**OW2**
Type	**Observation Well**
X-coordinate:	**200**
Y-coordinate:	**0**
Elevation (amsl):	**0**
Benchmark:	**0**
Penetration	**Fully**
R (effective radius):	**0.05**
L (screen length):	**3**
b (dist from bottom of well screen to top of aquifer):	**leave blank**
r (casing radius):	**0.025**

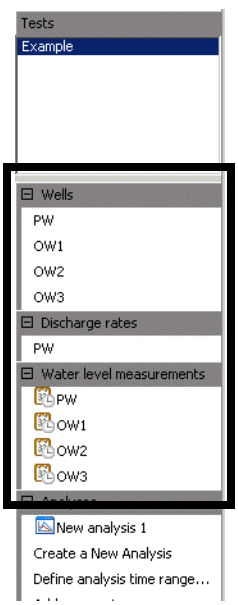
and

Name	**OW3**
Type	**Observation Well**
X-coordinate:	**1000**
Y-coordinate:	**0**
Elevation (amsl):	**0**
Benchmark:	**0**
Penetration	**Fully**
R (effective radius):	**0.05**
L (screen length):	**3**
b (dist from bottom of well screen to top of aquifer):	**leave blank**
r (casing radius):	**0.025**

Once completed, your wells table should appear as seen in the following figure.



In this manner, you can add as many wells as required to a project.



The new wells that are added to the project will appear in the **Wells** frame of the **Project Navigator** panel.

You will see there are now 4 wells in the **Wells** frame in the **Project Navigator** panel on the left side of the main window. In addition, wells that are set as type = Pumping Well, will appear under the **Discharge Rates** frame in the **Project Navigator** panel and all wells will appear under the **Water Level Measurements** frame in the navigation panel. Selecting a well in one of these frames will load the appropriate input page (tab) for the well. For example, clicking on PW1 under the **Discharge Rates** will activate the **Discharge** tab, and provide options for defining the pumping rates for this well. Clicking on OW1 under **Water Level measurements** will load the **Water Levels** tab, activate this well, and provide input fields for water level data.

In the next section you will specify the discharge rate for the pumping well, and add water level data for the observation wells.

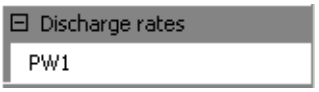
Before proceeding, save your project by selecting **File / Save As** from the main menu. Enter the name for the project "**Sample**", then continue.

2.1.2 Discharge Rates

The purpose of this step is to define the discharge (pumping rate) for the pumping well PW1.

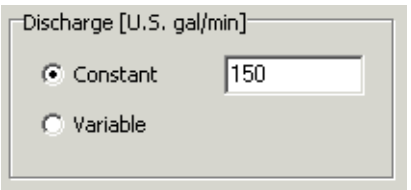
Click on the **Discharge** tab at the top of the window.

Or, from the **Project Navigator** panel, click on **PW1** under **Discharge Rates**.



In the top left corner of the window, select **PW1**. Enter the following discharge rate:

- **Constant** (radio button)
- Type: 150 in the adjacent field



2.1.3 Water Level Data

The next step in creating a pumping test is to add observation well water level data. AquiferTest provides several options for adding data to a pumping test including:

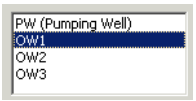
- Manually entering each data measurement
- Cut-and-pasting from the Windows clipboard
- Importing data from a text file or Excel spreadsheet (.xls)
- Importing data from an ASCII datalogger file (.asc, .txt) or Diver Datalogger (.MON) or Level Logger (.lev)

Entering Data Manually

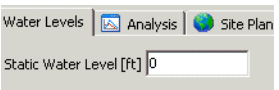
For OW1, the data will be entered manually.

[1] Select the **Water Levels** tab at the top of the window.

[2] Select **OW1** from the Wells list in the top left corner of the window; ensure this well is highlighted in blue before proceeding.



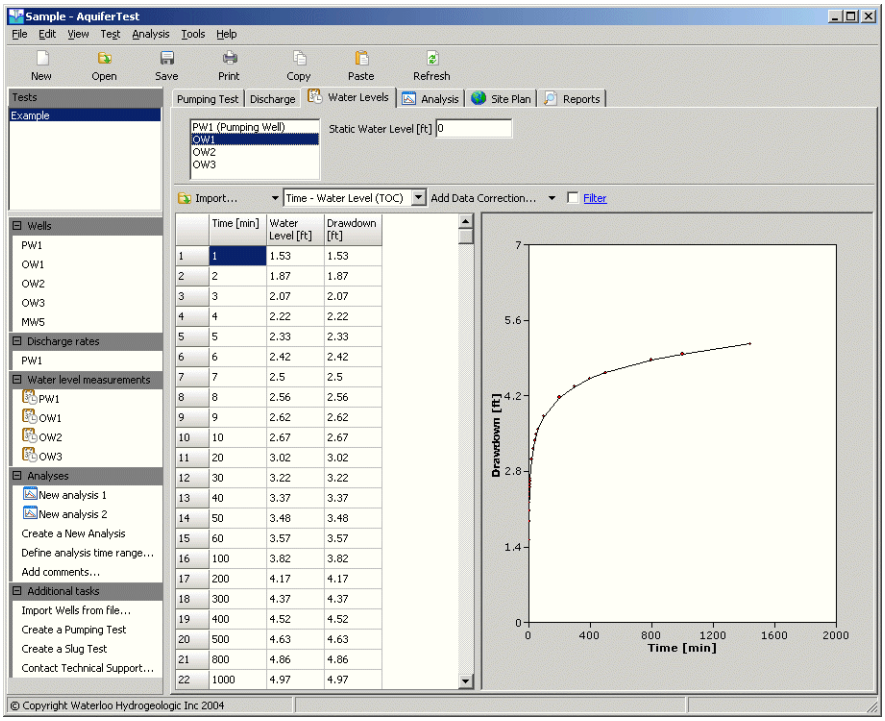
[3] Enter the **Static WL** of 0.



[4] In the **Time (min)** and **Depth to WL (ft)** columns, enter the following data. Press **Enter** after each value to move to the next field.

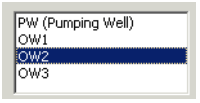
NOTE: Do not type anything in the **Drawdown** column.

Time [min]	Water Level [ft]
1	1.53
2	1.87
3	2.07
4	2.22
5	2.33
6	2.42
7	2.50
8	2.56
9	2.62
10	2.67
20	3.02
30	3.22
40	3.37
50	3.48
60	3.57
100	3.82
200	4.17
300	4.37
400	4.52
500	4.63
800	4.86
1000	4.97
1440	5.16

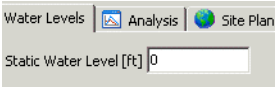


Importing Data from an Excel File

[1] In the **Water Levels** tab, select and highlight **OW2** from the Wells list.



[2] Enter the **Static WL** of 0



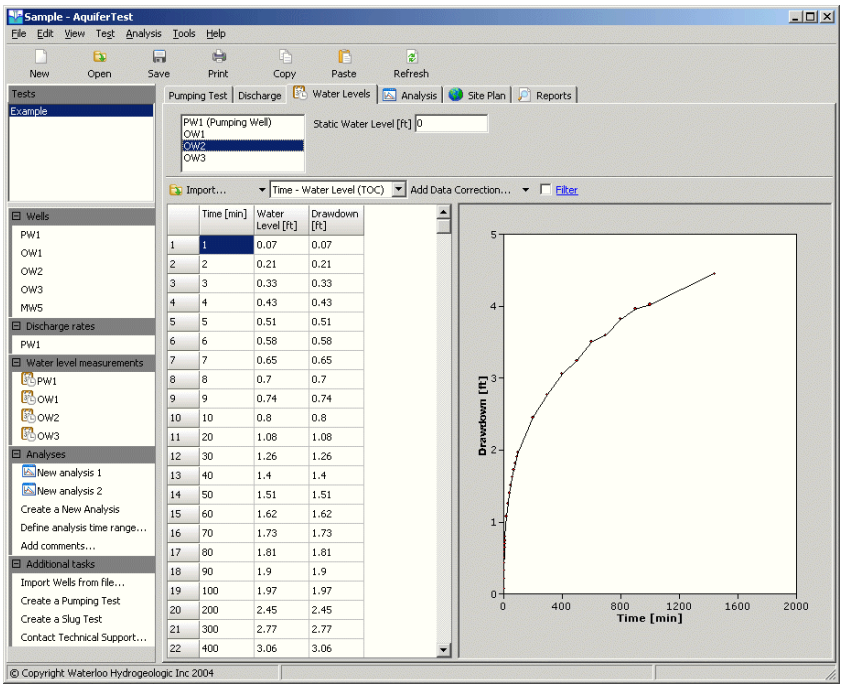
For this well, the data will be imported from an Excel file.

[3] Select **File/Import/Water Level measurements**

[4] A Windows Explorer dialogue will appear prompting you to select an Excel (.xls) file. Navigate to AquiferTest/ImportFiles and select **OW2_data.XLS**.

[5] Click **[Open]**. The data should appear in the grid.

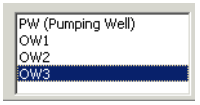
[6] The drawdown graph will be displayed as shown below:



For more information on importing data and formatting Excel files, please refer to Chapter 3: Import Water Levels...

Importing Data from a Datalogger File

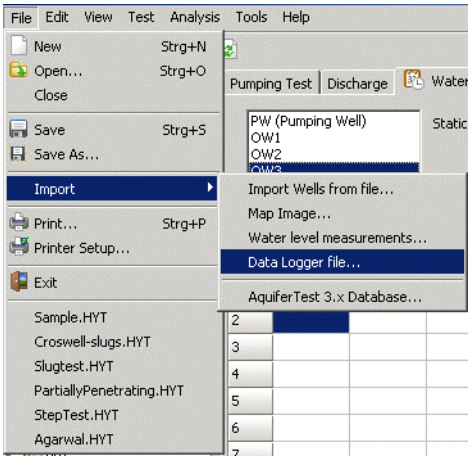
[1] In the **Water Levels** tab, select **OW3** from the Wells frame.



[2] Enter a **Static WL** of 0.

For this well, the data will be imported from a data logger file.

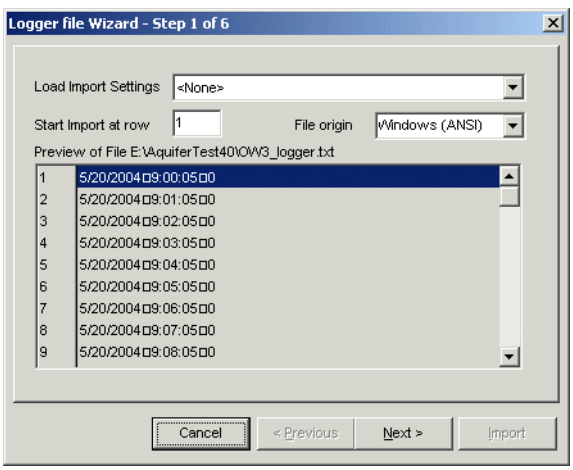
[3] From the Main Menu, click **File/Import** followed by **Data logger file...**



[4] In the Windows Explorer window that appears, navigate to AquiferTest/ ImportFiles and select **OW3_logger.txt**.

[5] Click **Open** to initiate the 6-step **Logger file Wizard**.

[6] The first step displays a preview of the data; set the **Start Import at row** to **1**.

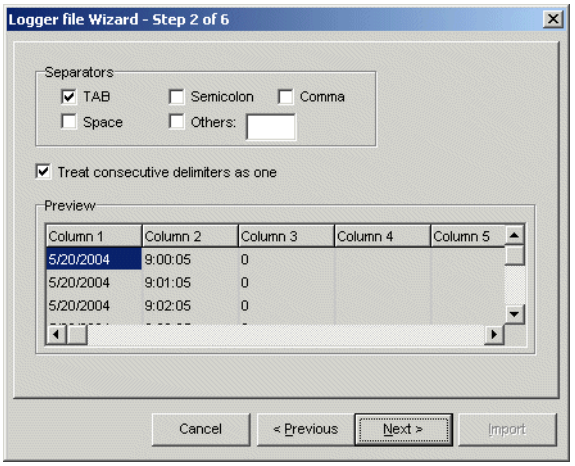


NOTE: The **Load Import Settings** allows you to load the settings specified during a previous import session.

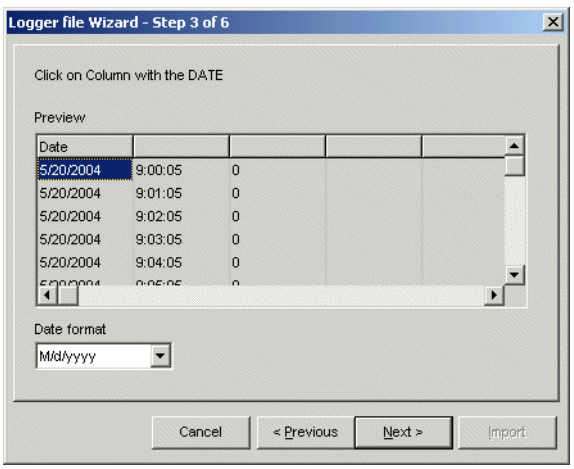
Click **[Next]**.

[7] **Step 2** will appear which allows you to specify the delimiter - ensure **TAB** is selected.

Click **[Next]**.



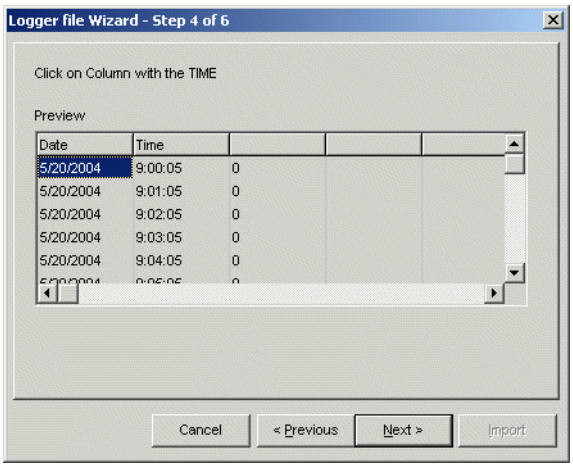
[8] **Step 3** will appear which allows you to specify which column contains the **Date**, and the **Date** format. Click on the column header which contains the Date data, (i.e. the first column, in the example below)



Click **[Next]**.

[9] **Step 4** will appear which allows you to specify the **Time** column. Click on the column that contains the Time data (i.e. the second column, in the example below).

Click **[Next]**.



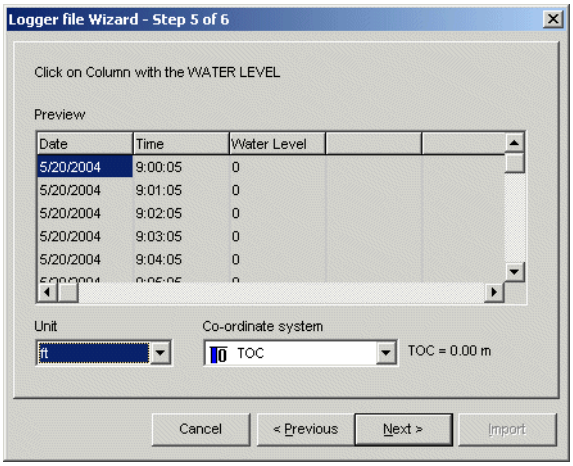
[10] **Step 5** will appear which allows you to specify the **Depth to water level (WL)** column, and also to set the units for the data;

In this example, click on the third column.

[11] Select the source **Units** for the file: **ft.**

If the source units are different from the test units, **AquiferTest** will automatically convert the data to the units used in the test.

[12] You can also specify the coordinate system to use for the data. In this example, leave the default **Top of Casing** datum (as seen below).



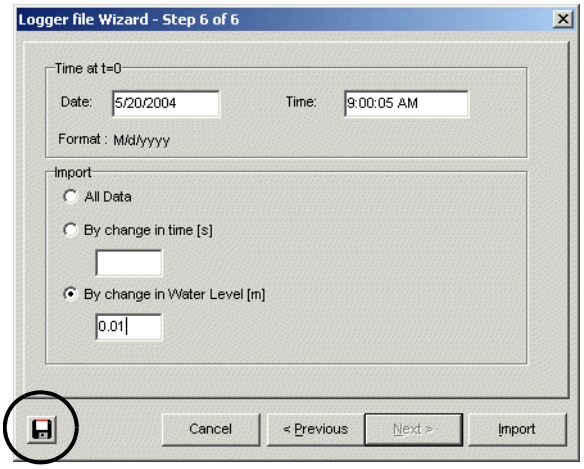
Click **[Next]**.

For more information on different types of the coordinate system, please see Chapter 3: Selecting a coordinate system.

[13] **Step 6** will appear which illustrates the **Date** and **Time** format that will be used for the data.

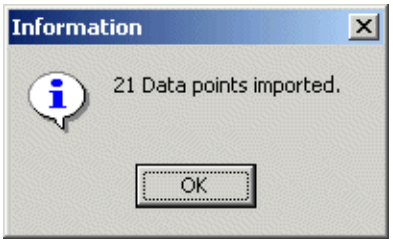
This final step also allows you to apply a filter to the data, which is an excellent idea when working with datalogger files. Generally datalogger files contain thousands of data points, however a large percentage of them are repeated values that are essentially useless. By applying a filter to the data set, you can reduce a large data set down to a reasonable few hundred data points.

The filter may also be applied after data import, in the **Water Levels** tab. For further description of this feature, please see Filter, page 65.



Circled above is the “Save import settings” icon. Using this feature you can save the settings you have used to load the logger file and recall them the next time a logger file is loaded.

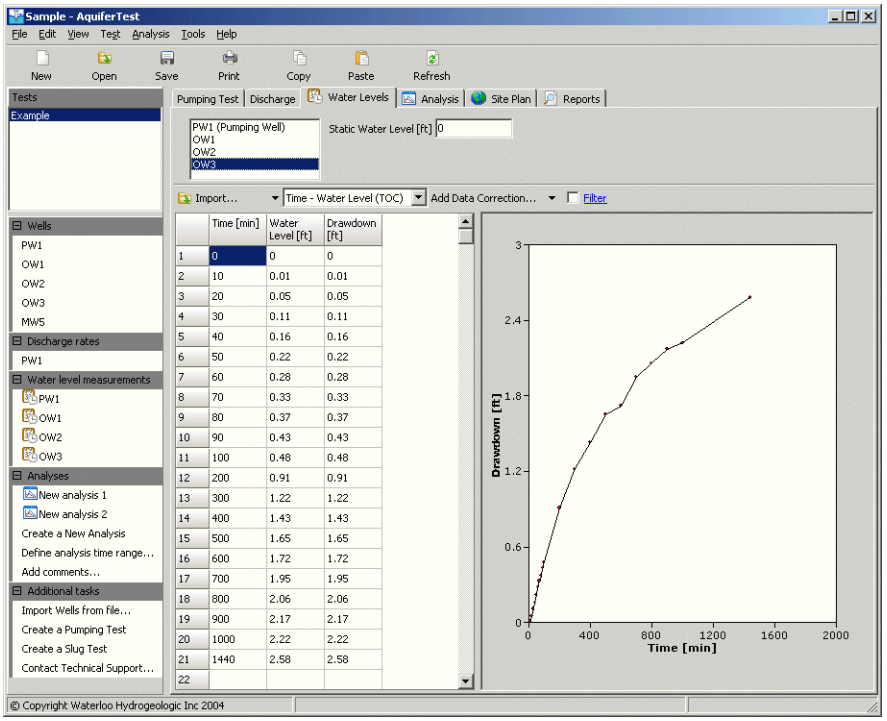
[14] Click **[Import]** to begin importing the data. Once completed, the following dialogue will appear.



[15] Click **[OK]** to complete the import process, and the data will be imported into the **Water Level** table.

[16] The graph of the **Time vs. Drawdown** for OW3 will be displayed as shown

below:



Now that you have imported one datalogger file and saved the process as a template, importing subsequent datalogger files of the same format can be extremely quick.

In the next section, you will learn how to create an analysis to examine the water level data that has been imported into the project.

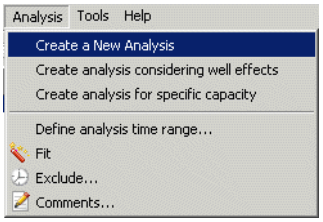
[17] To save the project, click **File / Save** from the main menu, or click on the (Save) button in the toolbar.

2.1.4 Creating a Pumping Test Analysis

The next step is to examine and analyze the data, and determine the aquifer parameters from the pumping test data.

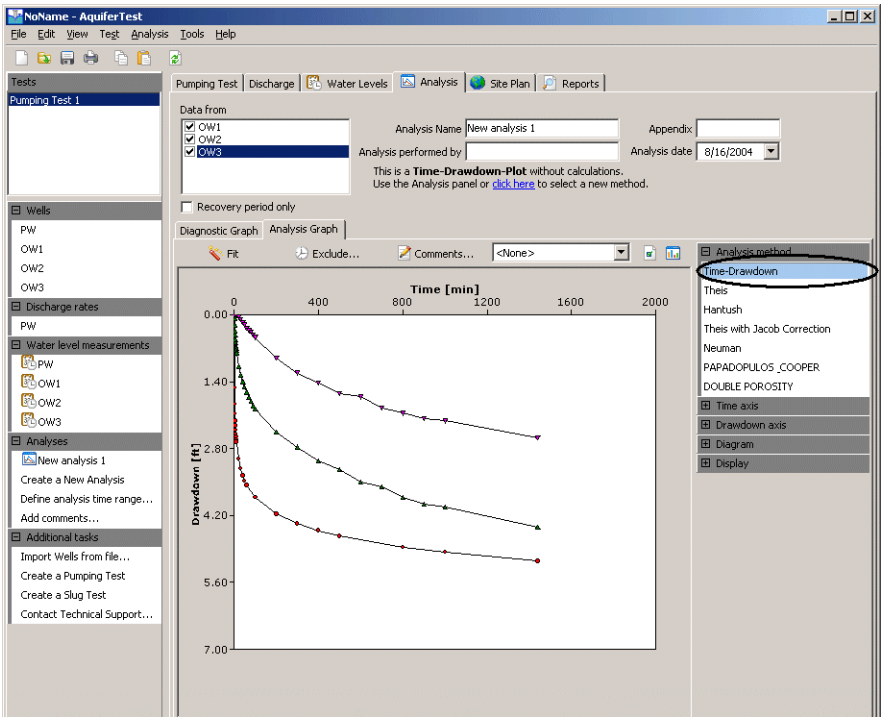
[1] From the main menu, select **Analysis/Create New Analysis** and the **Analysis** tab will be activated (alternately, click on **Create a New Analysis** under the

Analyses frame of the **Project Navigator**).



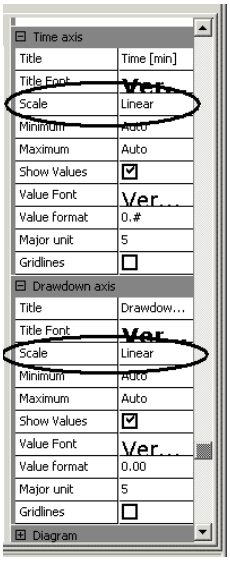
[2] Choose **Time-Drawdown** from the **Analysis method** frame of the **Analysis Navigator** panel.

[3] In the **Analysis Name** field, type “Time vs. Drawdown”



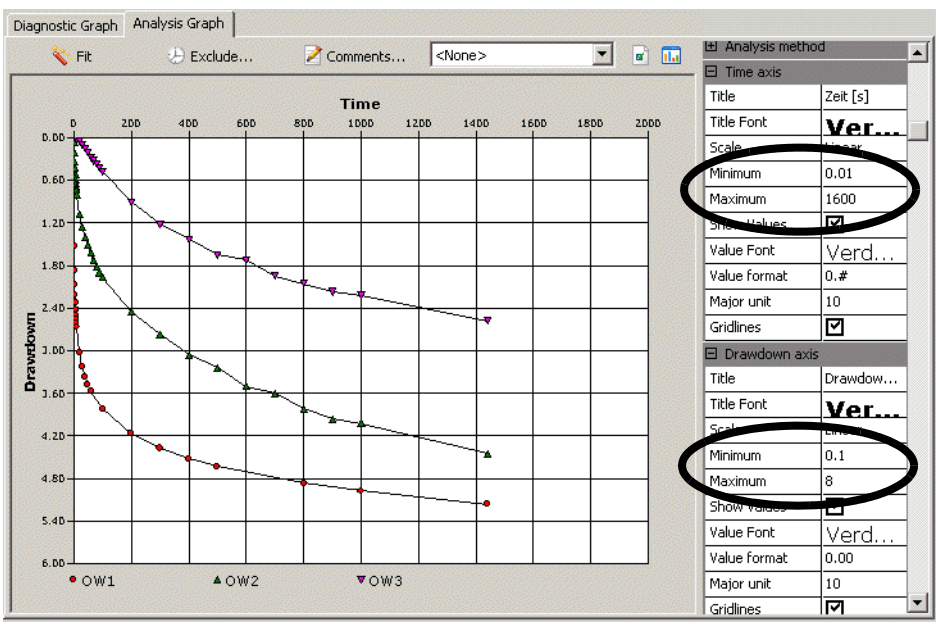
[4] Expand the **Time axis** and **Drawdown axis** frames and if desired, change the

scale from “Logarithm” to “Linear”



[5] Adjust the **Max** and **Min** fields in the above mentioned frames by highlighting the value (or word “Auto”) in the field and replacing it with a new value, so that the graph fits comfortably in the graphing area (see the image below for suggested values).

Your graph should now appear similar to the one shown below.



[6] Click on the

(Automatic Fit) button to perform an automatic fit for

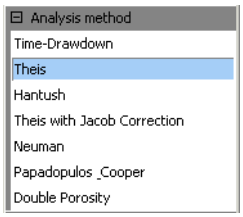
the selected well.

[7] Repeat this for each data set, by highlighting each well in the **Data from** window, then clicking on the

(Automatic Fit) button.

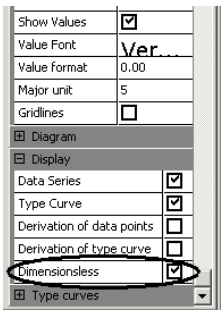
[8] To create a Theis analysis click **Analysis/Create New Analysis** from the **Main Menu** bar.

[9] In the **Analysis methods** frame of the **Analysis Navigator** panel choose **Theis.**



[10] In the **Analysis Name** field, type “Theis”

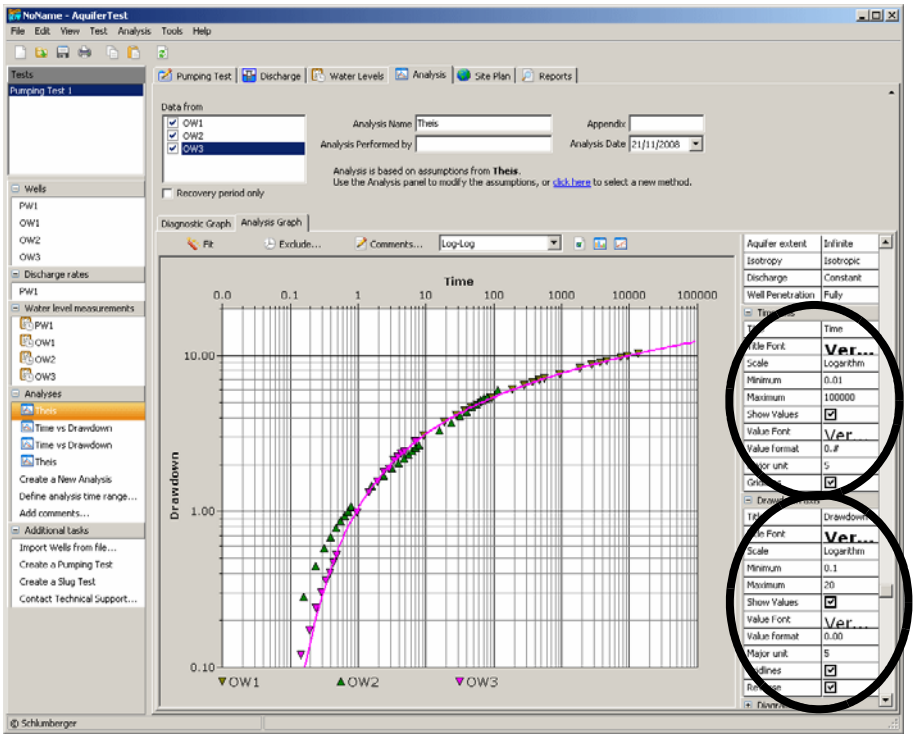
[11] Expand the **Display** frame and check the box beside “**Dimensionless**”



[12] This will display the Theis analysis on the traditional log-log plot.

[13] Perform an **Automatic fit** as described above. Your graph should look similar to

the one shown below.

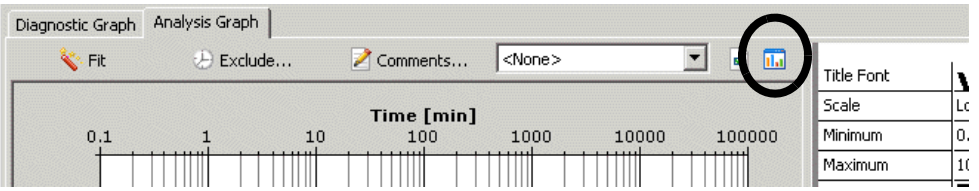


If necessary, modify the axis min and max values, as circled above.

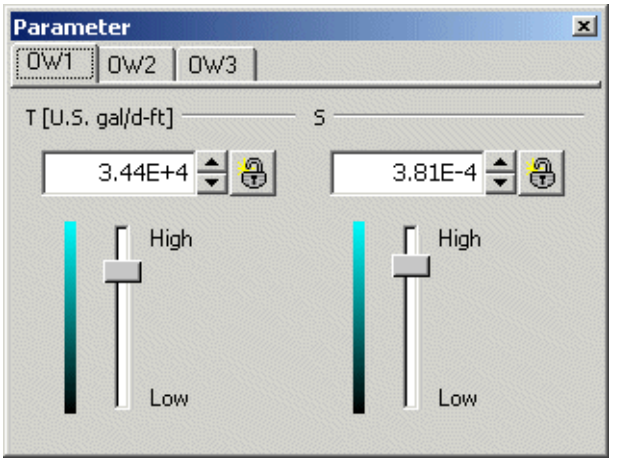
[14] The calculated Transmissivity and Storativity values are displayed in the **Results** frame for each well:

⊞ Analysis method	
⊟ Results - OW3	
T [U.S. gal/d-ft]	1.87E4
S	3.61E-4
⊟ Results - OW2	
T [U.S. gal/d-ft]	2.32E4
S	6.79E-4
⊟ Results - OW1	
T [U.S. gal/d-ft]	3.44E4
S	3.81E-4
⊞ Model Assumptions	
⊞ Time axis	
⊞ Drawdown axis	
⊞ Diagram	
⊞ Display	
⊞ Type curves	

The curve fit can be manually adjusted using the parameter controls; click on the (parameter controls) button located in the top right corner above the graph:



The following dialog will appear.



Parameter controls allow you to apply your own expertise and knowledge of the data by manually adjusting the curve fit and updating the values for Transmissivity and Storativity.

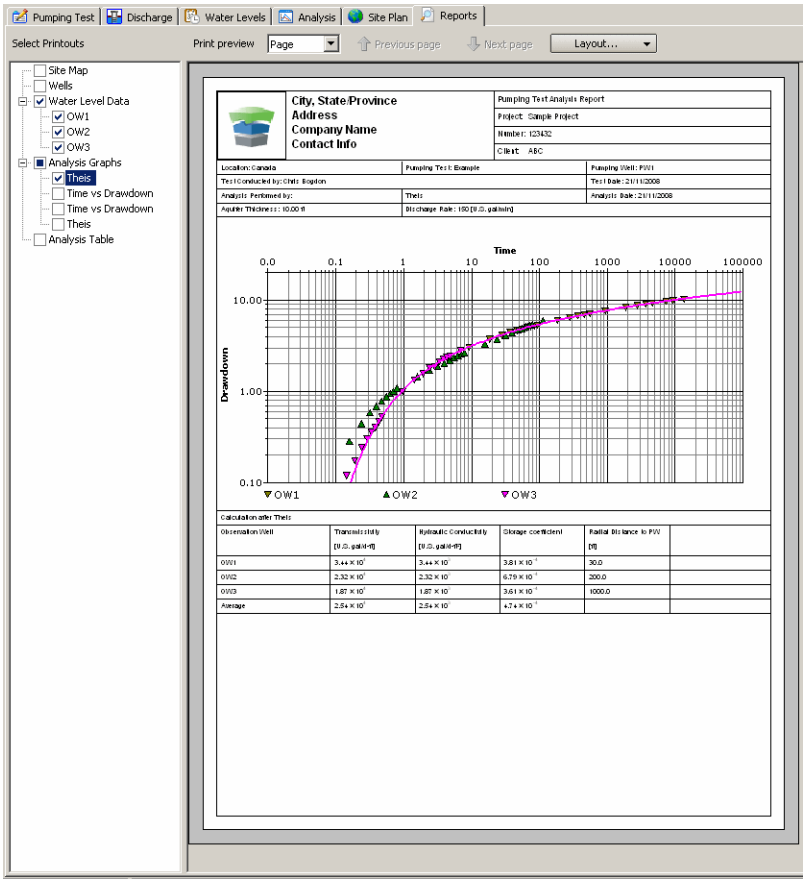
2.1.5 Reports

To print a report with the results, perform the following:

[1] Select **Reports** Tab

[2] In the **Select printouts** frame, expand any categories you wish to print, and select

the reports you wish to print



[3] Select **File/Print** or click on the (Print) button in the main toolbar.

This concludes the exercise for creating a pumping test. In the next section, we will examine the process of creating a slug test.

[4] Save your project before proceeding by selecting **File / Save**.

2.2 Creating a Slug Test

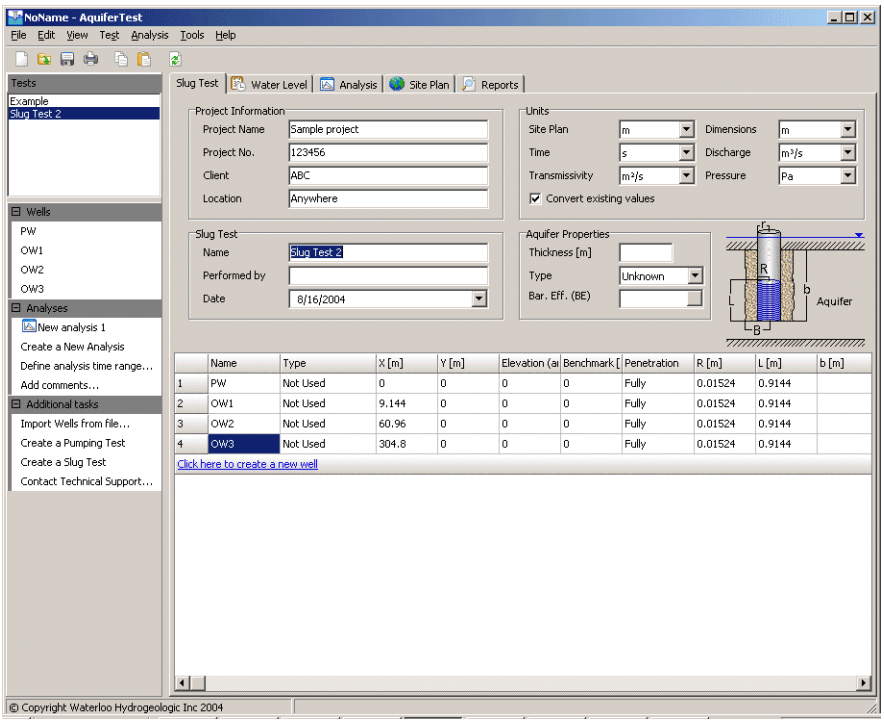
In this section you will learn how to create a slug test, set the slug test units, enter water level data for the test well, and finally how to create the Slug Test analysis and calculate the hydraulic conductivity.

The following instructions are presented with the assumption that you have gone through the “Chapter 2: Creating a Pumping Test” and the screenshots will reflect that.

For the slug test, the same sample project (Sample.HYT) will be used as in the first part of this exercise.

In this example, data is recorded at MW5, where a slug (bail) of water is removed and the water levels are recorded.

To create the slug test, select **Test/Create Slug Test** from the **Main menu**. This will load the **Slug Test** tab (the first page), as shown below.



The first step is to define the test information, units, and the test well.

2.2.1 Slug Test Information

The Project information (Name, Number, Client, and Location) is defined on a project level, and will be carried over from the previous pumping test.

Test Information

Enter the following new information for the slug test on the **Slug Test** tab:

Slug Test Information

Name:	**Sample Slug Test**
Performed by:	**Your Name**

Date:	**Test Date**
Aquifer Properties	
Thickness (m):	**10**
Type	**confined**
BE	**leave blank**

Units

AquiferTest allows you to store unique units for each pumping or slug test. In this example, you will define new units for the new slug test. Define the following units for this slug test:

Site Plan:	**m**
Dimensions:	**m**
Time:	**s**
Discharge:	***N/A**
Transmissivity:	**m^2/s**
Pressure:	***N/A**

* Units for **Discharge** and **Pressure** can be ignored, since these parameters are not required for slug tests.

Well Locations and Geometry

A new well must be defined for the slug test.

- Click "**Click here to create a new well**"

In the Wells grid at the bottom of the window, enter the following information for this well.

Name	**MW5**
Type	**Test Well**
X-coordinate:	**0**
Y-coordinate:	**0**
Elevation (amsl):	**0**
Benchmark:	**0**
Penetration	**Fully**
R (effective radius):	**0.05**
L (screen length):	**3**
b (dist from bottom of well screen to top of aquifer:	**leave blank**
r (casing radius):	**0.025**

The remaining fields can be left blank.

The ‘Pumping well b’ value is the distance from the bottom of the well screen to the top of the aquifer at the start time of the pumping test. In this example ‘b’ is not required, however this value is required to complete an analysis for partially penetrating wells.

NOTE: The well details for previously created wells have been automatically converted to the units scheme used in the slug test. If you click on your pumping test (“Example” in the **Tests** frame of the **Project Navigator** panel), those values would revert back, while the values for MW5 will be converted to the units of the pumping test.

2.2.2 Water Level Data

The next step in creating a slug test is to add the recorded water level data from the test well (MW5). As with pumping tests, you have several options for adding data to a slug test including:

- Manually entering each data point
- Cut-and-pasting from the Windows clipboard
- Importing data from a text file (.txt) or Excel (.xls) spreadsheet
- Importing data from a datalogger file (.asc, .txt, or .lev)

For this example, the data will be imported from an Excel file.

[1] Click on the **Water Level** tab at the top of the window.

[2] Enter the following information:

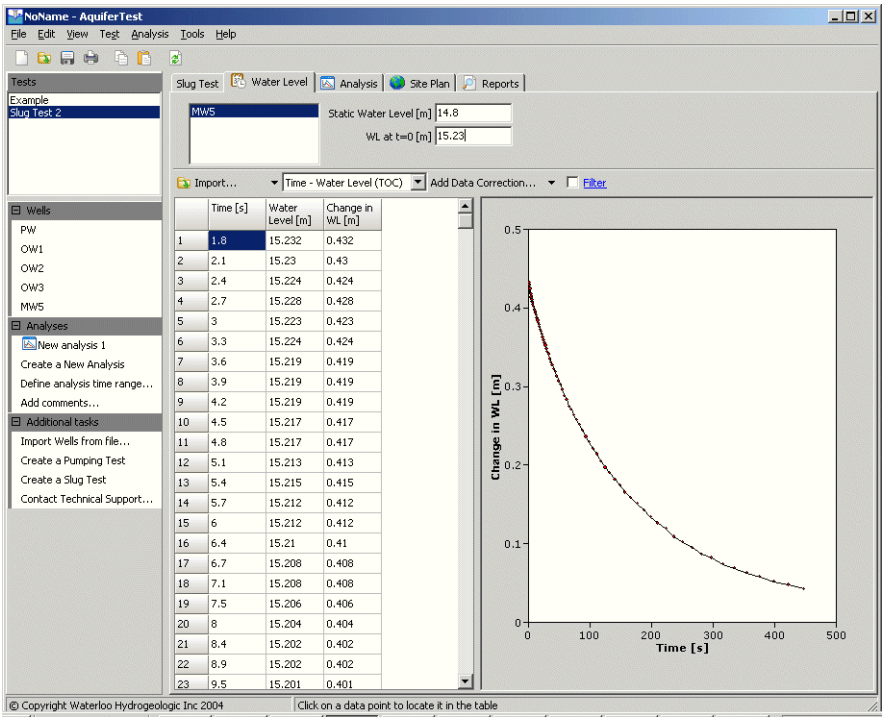
Static Water Level	**14.80**
Water level at t=0	**15.23**

[3] Select **File / Import / Water level measurements**

[4] Browse to the AquiferTest\ImportFiles folder, and locate the **MW5.xls** file.

[5] Highlight the file and click **[Open]**

[6] Click **Refresh** to display the change in water level data, and graph of Time vs. Change in Water Level. Once completed, your display should appear similar to the following figure:



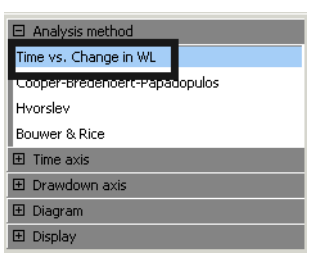
AquiferTest subtracts the **Depth to Static WL** value from each **Water Level** value, and produces a third column of data - **Change in WL** (as seen above).

2.2.3 Creating a Slug Test Analysis

Now that you have successfully defined the test details and imported water level data, you can analyze the data, and determine the conductivity.

[1] Select **Analysis/Create New Analysis** from the **Main menu**, and the **Analysis** tab will be activated. (Alternately, click on **Create a New Analysis** under the **Analyses** frame).

[2] Locate the **Analysis** frame, on the right side of the window. Under the **Analysis method** frame, select **Time vs. Change in WL**



[3] In the **Analysis Name** field (above the graph), type "**Time vs. Change in WL**".

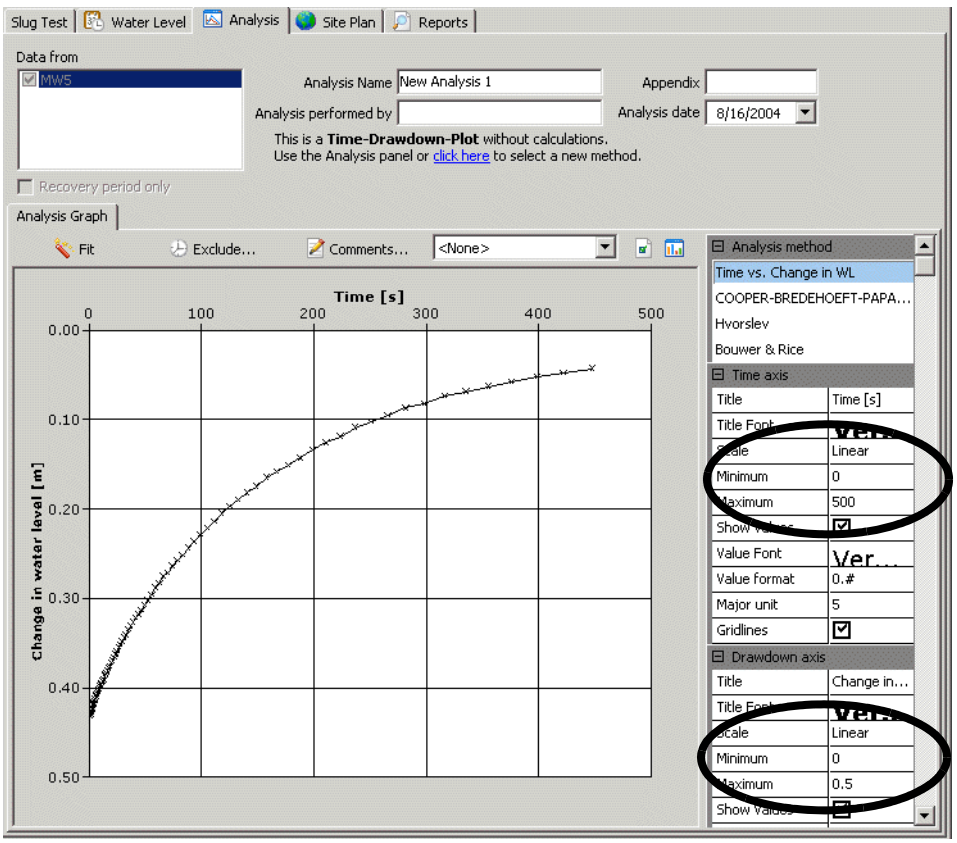
[4] Define the following properties for the plot axes:

Time axis

- **Scale** = Linear
- **Min** = 0
- **Max** = 500

Change in Water Level

- **Scale** = Linear
- **Min** = 0
- **Max** = 0.5



[5] Using the steps listed above, create a new analysis for this data set.

[6] Select **"Hvorslev"** from the **Analysis methods** frame of the **Analysis Navigator** window.

[7] Type "**Hvorslev**" in the **Analysis name** field at the top of the window.

[8] Define the following properties for axes:

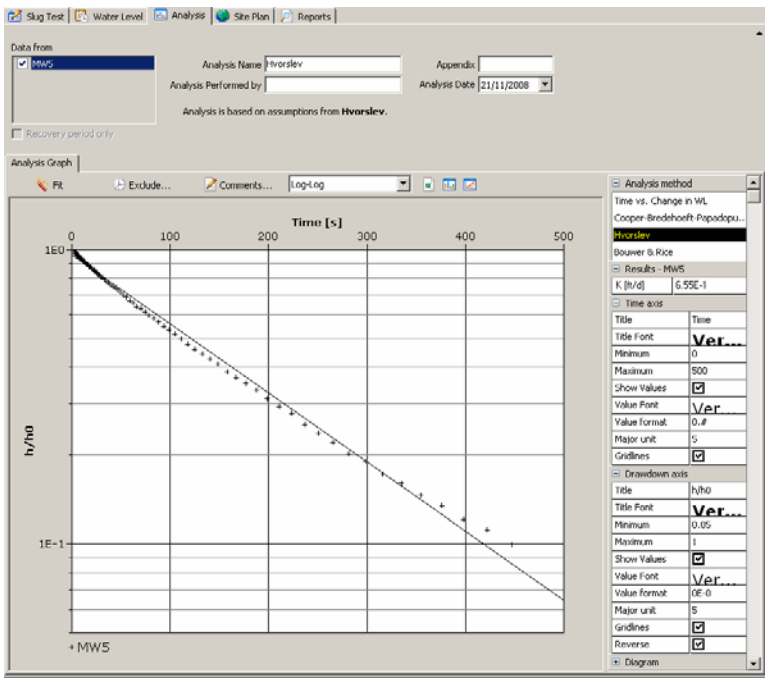
Time

- **Min** = 0
- **Max** = 500

Drawdown

- **Min** = 0.05
- **Max** = 1
- **Reverse** = Checked

[9] Display the grid lines for both axes and your graph should now look similar to the one shown below:



The calculated **K** value can be found in the **Results** frame of the **Analysis Navigator** panel; for this example, K = **2.31E-6** m/s

[10] To create a Bouwer & Rice analysis of the same data set, create a new analysis and choose **Bouwer & Rice** from the **Analysis methods** frame of the **Analysis Navigator** panel.

[11] Type “Bouwer & Rice” in the **Analysis name** field.

[12] Define the following properties for the axes:

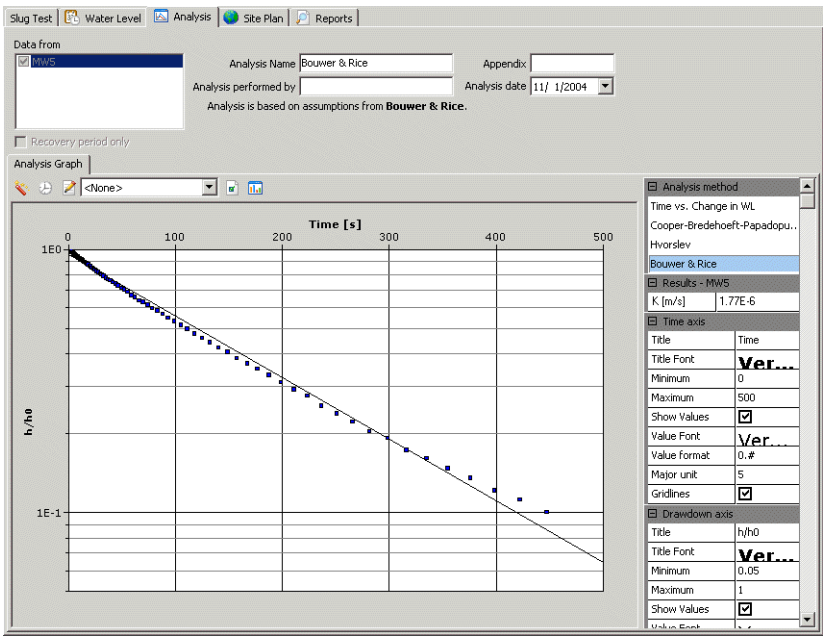
Time

- Min = 0
- Max = 500

Drawdown

- Min = 0.05
- Max = 1
- Reverse = Checked

[13] Display the grid lines for both axes and your graph should look similar to the one shown below:



The calculated **K** value can be found in the **Results** frame of the **Analysis Navigator** panel; for this example, K = **1.77E-6** m/s

NOTE: The curve fit, and resulting conductivity value (K) can be manually adjusted using the **Parameter Controls** as described in “Chapter 3: Parameter Controls”.

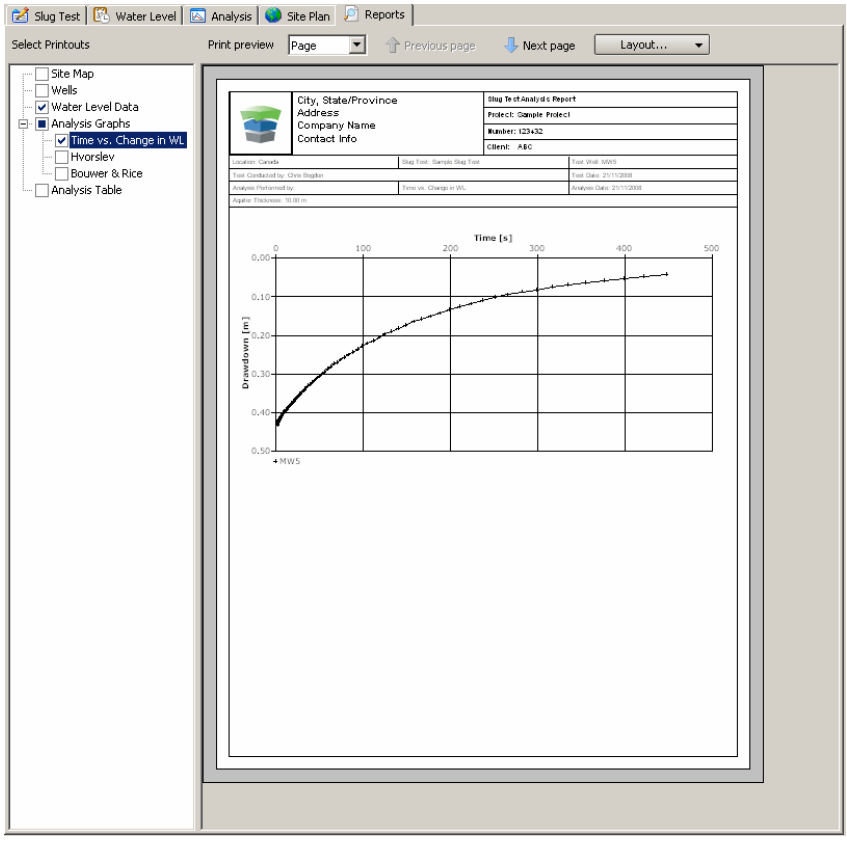
NOTE: It is not necessary to create a new analysis each time you want to see a new analysis. Simply change the analysis type in the **Analysis method** frame of the **Analysis Navigator** panel. Creating new analysis windows is helpful, however, if you wish to easily compare and print a hard copy of these analyses.

2.2.4 Reports

To obtain relevant printouts, click on the **Reports** tab. From this window you can print out any information that you have entered or derived through analyses. For example, to print the dataset for MW5, as well as the Hvorslev and the Bouwer & Rice analyses complete the following:

[1] Expand the Navigator tree in the **Reports** tab.

[2] Check the boxes beside **Water Level Data**, **Hvorslev**, and **Bouwer & Rice.** Your **Reports** window should now look similar to the one shown below:



[3] From the main menu, select **File / Print** and all selected reports will be sent to the printer.

This completes **Chapter 2: Getting Started**; we hope it has been useful for you. For additional practice with **AquiferTest**, please refer to Chapter 7: Demonstration Exercises and Benchmark Tests.

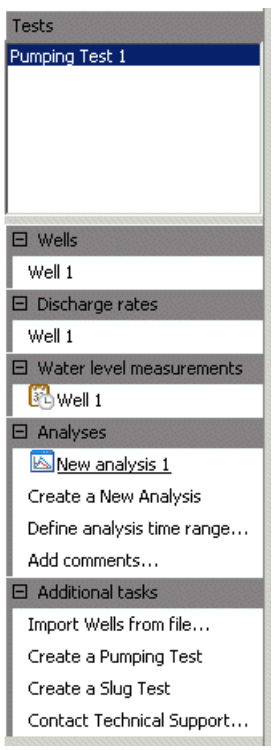
3

General Info and Main Menu Bar

3.1 General Info

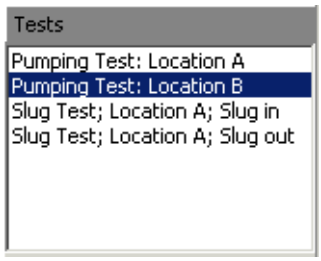
3.1.1 Project Navigator Panel

The **Project Navigator** allows you to easily move around the project as it contains links to most of its major components. The **Project Navigator** contains following frames: **Tests**, **Wells**, **Discharge rates**, **Water level measurements**, **Analyses**, and **Additional tasks.**



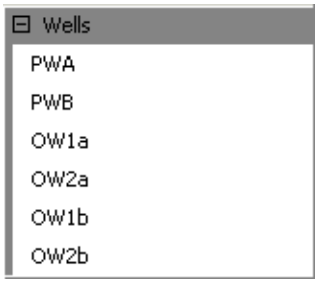
Tests

This frame contains all of the pumping tests and slug tests for the current project. Assign descriptive names to each test to allows for easy recognition.



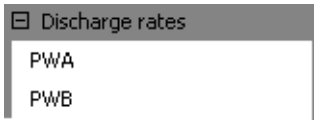
Wells

This frame lists all the wells that are present in the project. Clicking on a well will activate the first tab of the current test and highlight the row that contains this well in the wells grid.



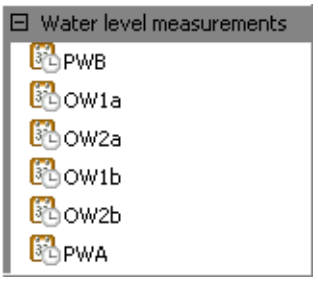
Discharge Rates

This frame lists all the PUMPING wells used in the current test. Clicking on the well in this frame will activate the **Discharge** tab of the current test (applicable to pumping tests only).



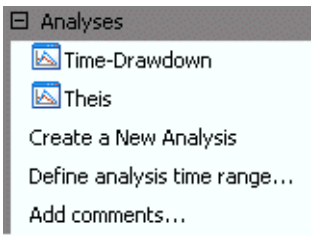
Water level measurements

This frame lists all the wells (pumping and observation) used in the current test. Clicking on the well in this frame will open the **Water Levels** tab of the current test.



Analyses

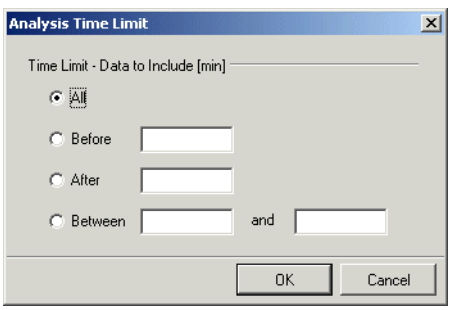
This frame lists the analyses that have been done for the current test. Clicking on an analysis in this frame will open the **Analysis** tab of the current test.



The Analyses frame also contains links to some of the more common functions used in a test.

- **Create a New Analysis**
  - creates a new analysis for the current test
- **Define analysis time range...**
  - allows you to select a time range for the current analysis (instead of using an entire dataset) in case some data points are unusable for the curve fit.

Clicking on this link will produce the following dialog:



In this dialog, specify the time range that contains the data that you wish to INCLUDE in the analysis.

- **Add comments...**
  - allows you to add comments about the current analysis

Additional tasks

Provides links to some of the most commonly used features of **AquiferTest**.

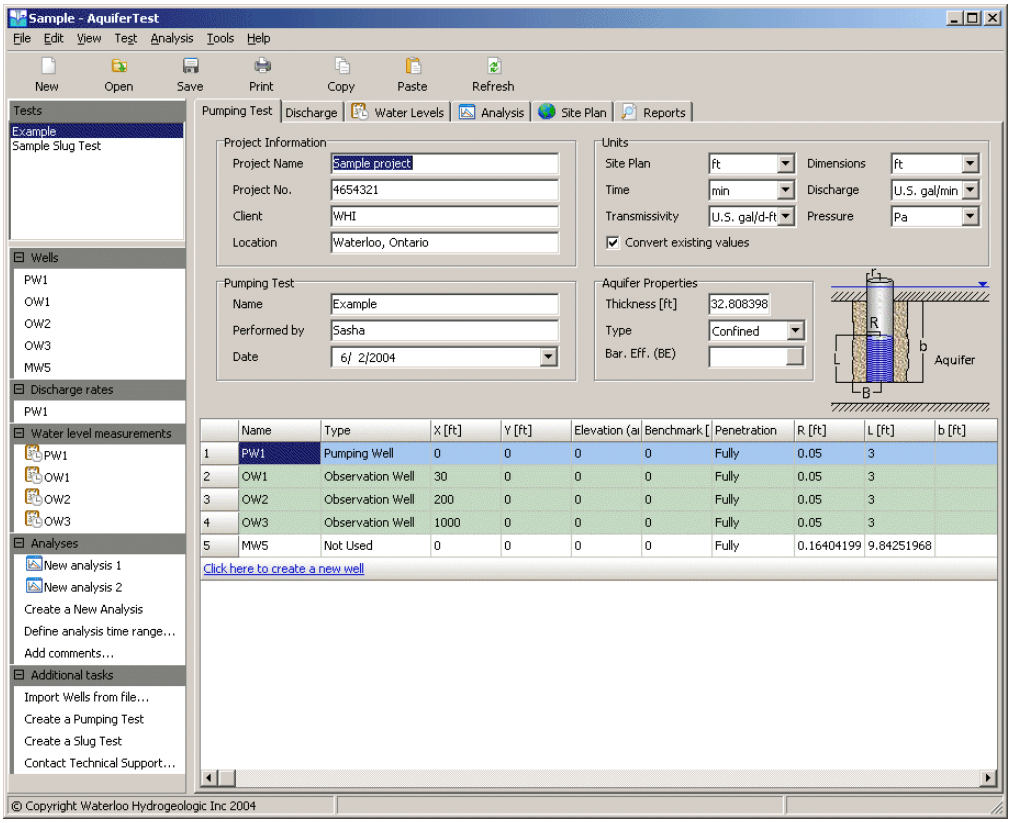
- **Import wells from file...**
  - allows you to import well data from an Excel or a Text file. Clicking on this link will initiate the same process as selecting **File/Import/Import Wells from file...** from the Main menu. For more details, see page 86.
- **Create a pumping test...**
  - allows you to create a new pumping test in the project
- **Create a slug test...**
  - allows you to create a new slug test in the project
- **Contact technical support...**
  - displays information on how registered users can contact WHI technical support

3.1.2 Data Entry and Analysis Tabs

The data entry and analysis window is organized into five or six tabs depending on the type of test used. A pumping test has the following tabs: **Pumping Test**, **Discharge**, **Water Levels**, **Analysis**, **Site Plan** and **Reports**. If slug test is selected there are only five tabs, since there is no discharge in the slug test. Also, in the slug test the **Pumping Test** tab is replaced by the **Slug Test** tab.

Pumping Test Tab

This tab allows you to lay the groundwork for the test. It contains such information as project name, location, date, the units of the test, and aquifer and well parameters.



Project Information

In this frame, specify the general information about the project, such as the project name, number, person or organization for whom the project was performed, and the location of the test.

Pumping Test

In this frame, provide a unique test name to facilitate navigation and your name as a signature for the output. The **Date** reflects the date the test was conducted; use the pull-down calendar to select a new date.

Units

In this frame, specify the units for the collected data, and optionally convert the values to different units for the output using the **Convert existing values** feature described below.

- **Site Plan:** specify units in which the well XY coordinates, elevation, and benchmark were measured. Available units are:

- **Dimensions:** specify the units in which the well and aquifer parameters were measured. Available units are:

- **Time:** specify the units in which the time was recorded. Available units are:

- **Discharge:** specify the units in which discharge was recorded. Available units are:

- **Transmissivity:** specify the units in which the transmissivity values will be calculated. Available units are:

- **Pressure**: specify units in which pressure data was recorded. Available units are:

The **Convert existing values** checkbox allows you to convert the values to the new units without having to calculate and re-enter them manually.

On the other hand, if you created a test with incorrect unit labels, you can switch the labels by de-selecting the **Convert existing values** option. That way, the physical labels will change but the numerical values will remain the same.

NOTE: The default units for new tests can be defined in the **Tools/Options/General** window.

Any field that prompts you for (or displays calculated) values shows the units used in square brackets [ ] unless the value is dimensionless.

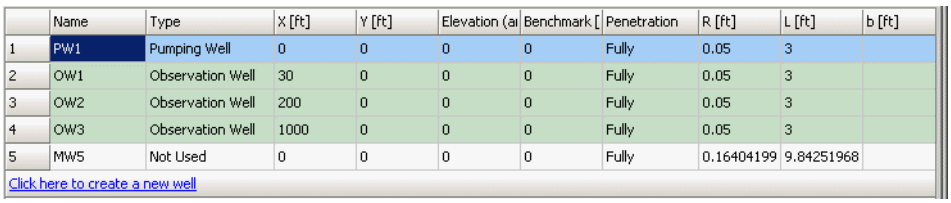
Aquifer Properties

In this frame, enter aquifer parameters such as **Thickness**, **Type** (Confined, Unconfined, Leaky, Fractured, Unknown), and **Barometric Efficiency**.

The diagram beside the frame displays different well geometry parameters that you will be required to enter to describe the wells used in the project.

Wells Grid

This table contains the information about well geometry and location of each well in the project.



	Name	Type	X [ft]	Y [ft]	Elevation (a	Benchmark [	Penetration	R [ft]	L [ft]	b [ft]
1	PW1	Pumping Well	0	0	0	0	Fully	0.05	3	
2	OW1	Observation Well	30	0	0	0	Fully	0.05	3	
3	OW2	Observation Well	200	0	0	0	Fully	0.05	3	
4	OW3	Observation Well	1000	0	0	0	Fully	0.05	3	
5	MW5	Not Used	0	0	0	0	Fully	0.16404199	9.84251968	

Click here to create a new well

- **Name**: provide a unique name for each well
- **Type:** define the type of well. In a pumping test, the available types are:
  - Pumping well
  - Observation well
  - Piezometer
  - Not used

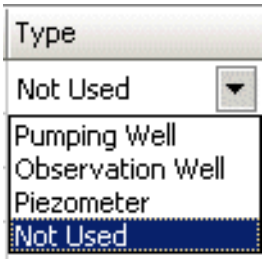
  while in a slug test the available types are:

  - Test well
  - Not used

  NOTE: In a slug test, only one well can have the “Test Well” status. To add additional wells, create new slug tests.

The Default setting for the first well in the project is Pumping well. The default setting for any well created thereafter is Observation well (or Test Well, for a slug test). To

change the well type, activate the **Type** field of the desired well and click again to produce a pull-down menu. From the menu choose the desired well type.

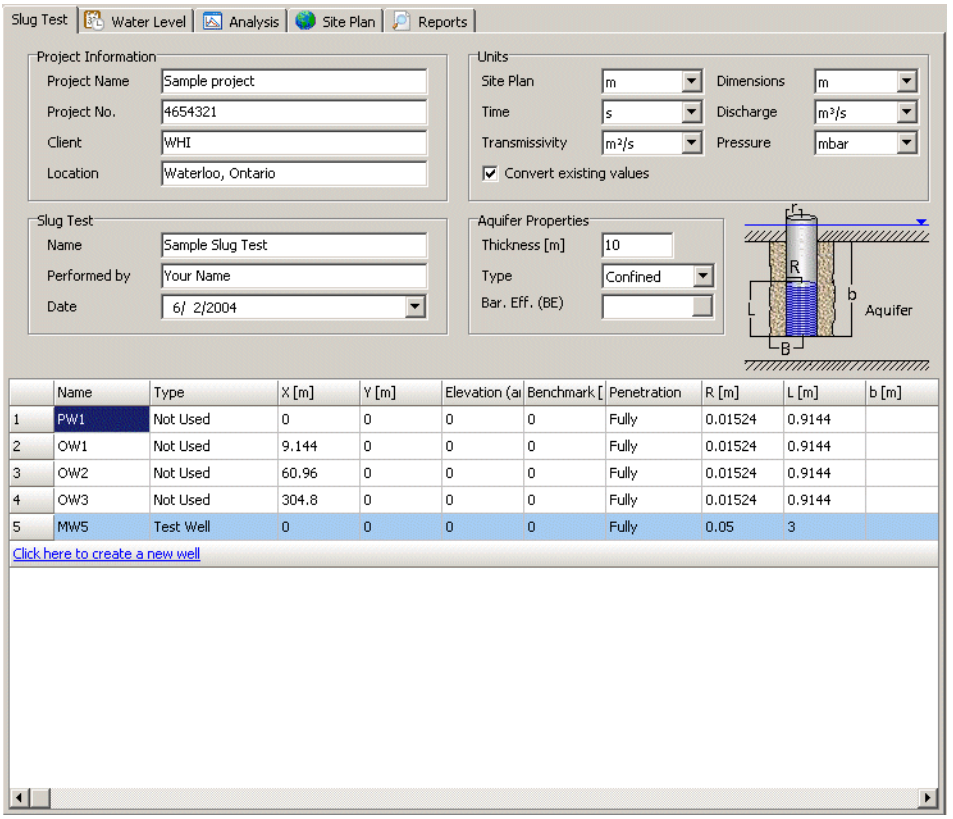


- **X [ ]** - X coordinate of the well
- **Y [ ]** - Y coordinate of the well
- **Elevation (amsl) [ ]** - well elevation relative to sea-level
- **Benchmark [ ]** - well elevation relative to a benchmark
- **Penetration** - penetration type of the well (fully penetrating or partially penetrating). The default is a Fully penetrating well.
- **R [ ]** - the screen radius
- **L [ ]** - screen length
- **b [ ]** - distance from the top of the aquifer to the bottom of the screen
- **r [ ]** - casing radius
- **B [ ]** - borehole radius
- **n** - gravel pack porosity [%]
- **Use r(w)** check-box allows you to decide whether to use the effective radius. The default setting is UNchecked.

Slug Test Tab

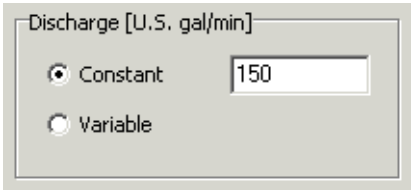
The **Slug Test** Tab contains the same frames as the **Pumping Test** tab. Project information is carried over in new tests. The fields in the Units, Slug Test, and Aquifer Properties frames return to their default values.

All wells created outside of the slug test change their type to “Not Used”. Any well created in the slug test will have a default type of “Test Well”.

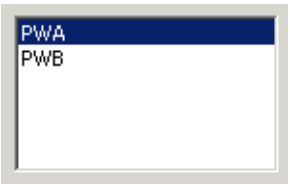


Discharge (Pumping Test only)

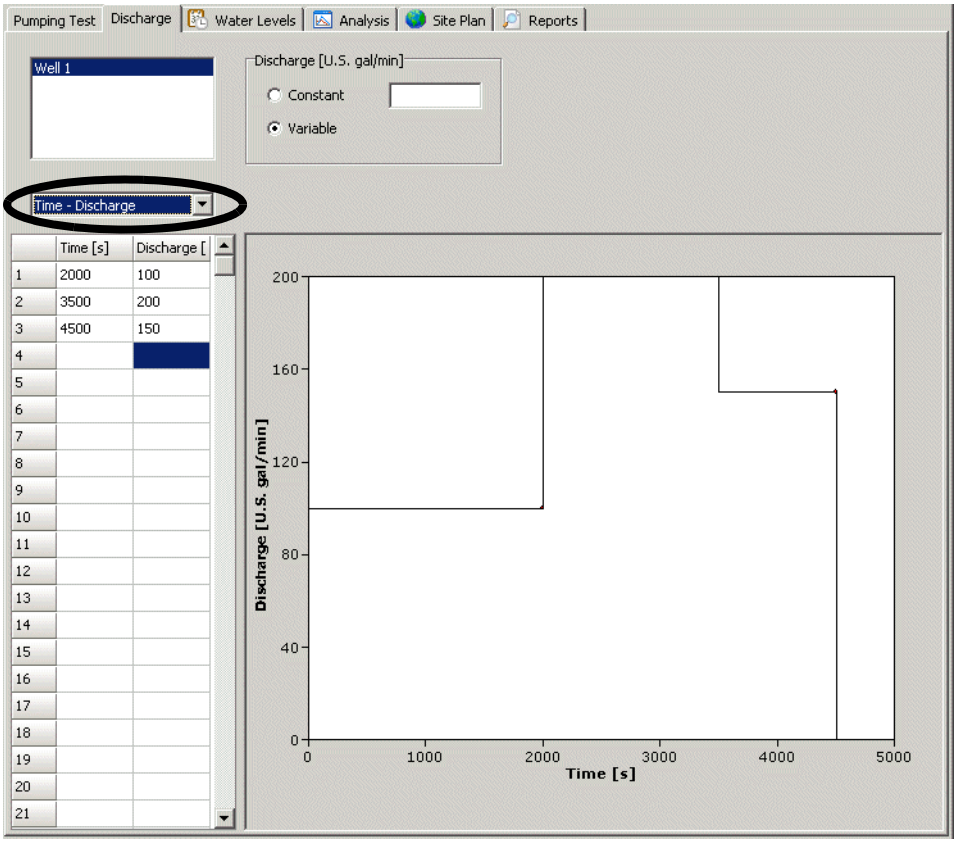
This window allows you to specify the type of discharge (constant or variable), and the discharge rate for one or more pumping wells.



You must select a pumping well for which the discharge data is to be entered.

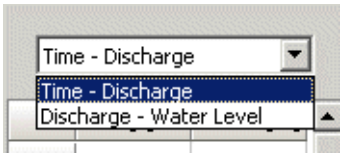


If the discharge is variable, this tab is used to enter the time periods and values for the discharge. AquiferTest also presents the time/discharge data graphically as it is entered.



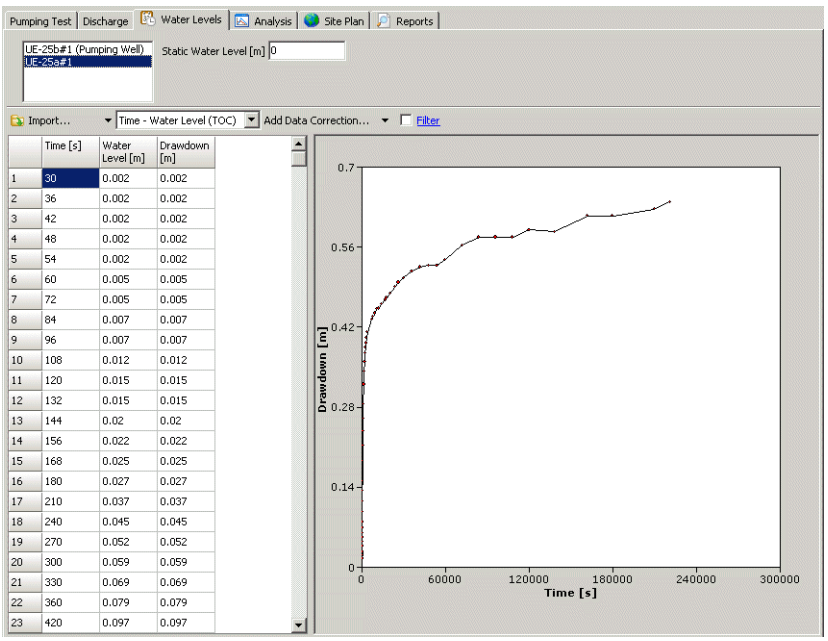
NOTE: **AquiferTest** will not allow you to enter any information in the discharge table until “Variable” (radio button) is selected in the **Discharge** frame, i.e. the discharge table (time and discharge columns) is active only if “Variable” is selected as the discharge type.

Under the wells list, there is a drop-down menu where you can switch from the default **Time vs. Discharge** to **Discharge vs. Water Level**. Discharge - Water Level data is required only for a single-well Specific Capacity analysis. See Chapter 4: Specific Capacity, for more details.

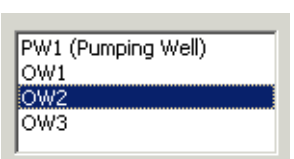


Water Levels Tab

In this tab, enter the water level data for the pumping and observation wells in the test. Options in this tab allow you to import a dataset from an Excel or a data logger file, set up the coordinate system, add data correction, and filter the data.



To proceed with data entry you must first select a well for which the data will be entered.



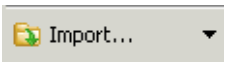
The data can be entered in any of the following ways:

- manually
- cut-and-paste from Windows clipboard

- importing data from a text file or Excel spreadsheet (*.txt, *.xls)
- importing data from an ASCII datalogger (*.asc, *.txt) or Level Logger (*.lev), or Diver Datalogger (.MON)

Import

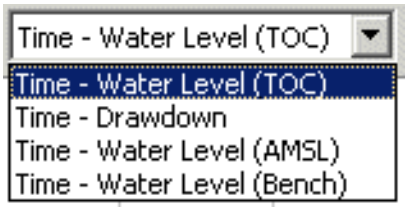
The **Import** button is a shortcut to importing an Excel or a data logger file.



For more information on importing data, see “Import” on page 86.

Selecting a coordinate system

To the right of the **Import** button is a drop-down menu where you can choose the coordinate system for the water level data. The options are:



Time - Water Level (TOC) - Top of Casing system:
Using the **Top of Casing Datum**, the top of the casing (TOC) elevation is designated as zero, and the data will be imported as measurements from the top of the well casing to the water level (i.e. depth to water level, the traditional format). After you import/enter the data, you must enter a value for **Depth to static water level**. Then click on the **Refresh** icon and **AquiferTest** will make the appropriate drawdown calculations, and plot the data on the graph.

Time-Drawdown:
Using the Time-Drawdown system, enter the drawdown data instead of the depth to water levels.

Time - Water Level (AMSL):
Using the **Sea-Level Datum**, the top of casing (TOC) elevation is designated as the Elevation (amsl) you have entered for that well. **AquiferTest** will read this elevation from the value you have input in the Wells table. After you import/enter the data, you must enter the value for the **Static Water Elev**. Then click on the **Refresh** icon and AquiferTest will make the appropriate drawdown calculations.

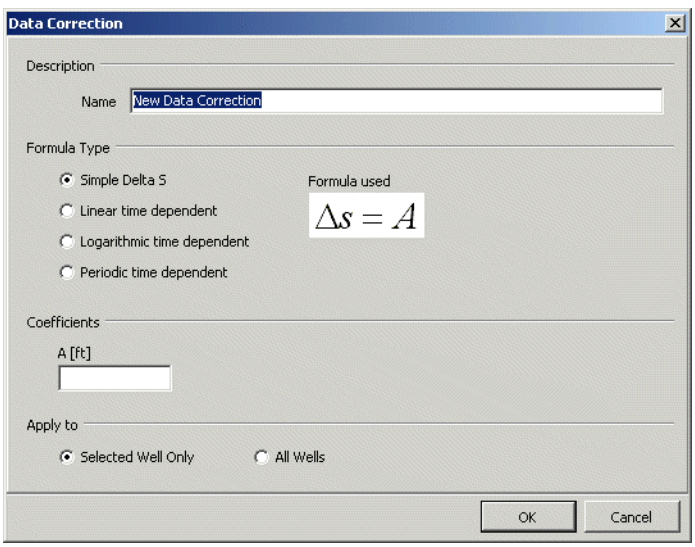
Time - Water Level (Benchmark):
Using the **Benchmark Datum**, the top of casing (TOC) elevation is designated as the benchmark elevation you have entered for that well. This elevation is relative to an arbitrary benchmark that would have been established during a site survey.

AquiferTest will read this elevation from the value you have input in the Wells table. After you import/enter the data, you must enter the value for the **Static Water Elev**. As with the sea-level datum, **AquiferTest** will make the appropriate drawdown calculations by calculating the difference between the static water level elevation and the water levels recorded during the test.

Add Data Correction

The data correction drop-down menu is located to the right of the **Coordinate system.** Using this menu you can add a user-defined data correction, trend correction, or barometric correction to the dataset. For more details, see Chapter 5: Data Pre-Processing.

[1] To add a **User defined (Custom) correction** click on the button **Add data correction** itself (not the down-arrow beside it). The following dialog is displayed:



In this dialogue, choose the type of correction you wish to implement by selecting the appropriate radio button. As you do so, a formula is displayed on the right hand side of the dialogue, and fields for variables involved in that formula appear below. Define values for the required variables and choose whether to apply the correction only to the currently selected well or to all wells in the pumping test.

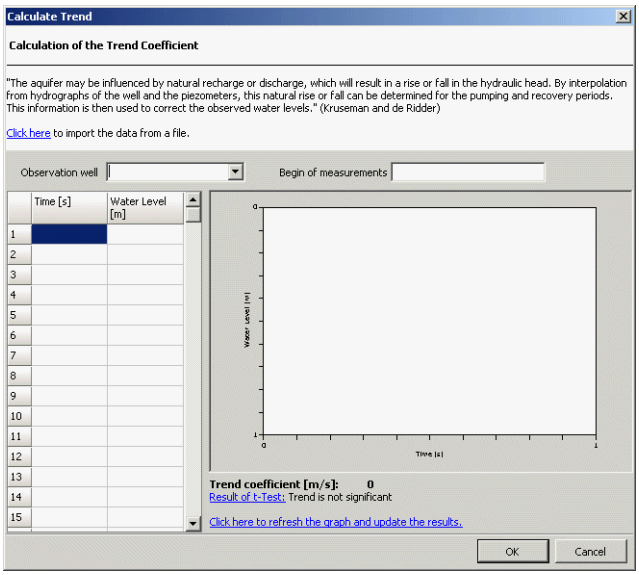
When finished, click **[OK]** to apply the correction and return to the **Water Levels** tab.

For more details, see Chapter 5: Customized Water Level Trends

[2] To add a **Trend correction** to the data, select the well and dataset, and select

Trend Correction from the **Add data correction** drop-down menu:

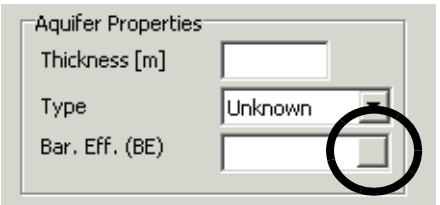
The following window will appear:


Calculate Trend
Calculation of the Trend Coefficient
"The aquifer may be influenced by natural recharge or discharge, which will result in a rise or fall in the hydraulic head. By interpolation from hydrographs of the well and the piezometers, this natural rise or fall can be determined for the pumping and recovery periods. This information is then used to correct the observed water levels." (Kruseman and de Ridder)
Click here to import the data from a file.
Observation well
Begin of measurements
Time [s]
Water Level [m]
Trend coefficient [m/s]: 0
Result of t-Test: Trend is not significant
Click here to refresh the graph and update the results.
OK
Cancel

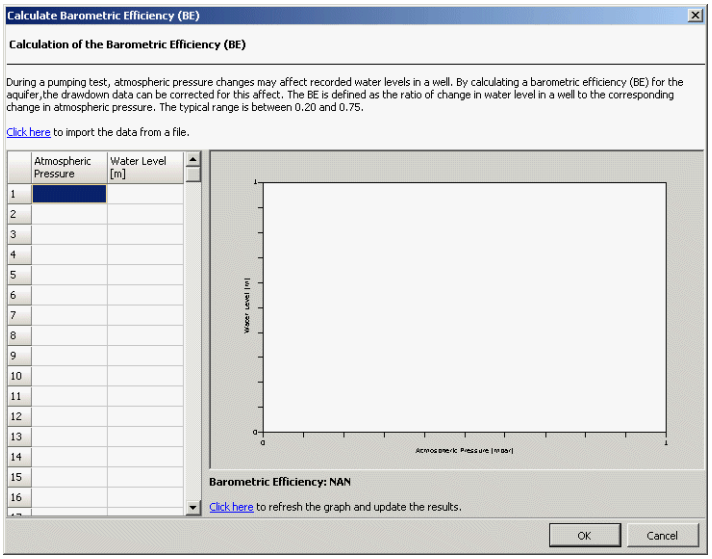
Manually enter data in the grid or follow the **Click here** link above the table to import a file that contains the time vs. water level correction data. Once loaded into the table, the datapoints will be displayed on the graph to the right of the table and the trend coefficient will be calculated. The trend significance is determined by a t-test statistical analysis. Press **[OK]** to apply the correction to your data and two new columns will appear in your water levels table - **Trend Correction** and **Corrected drawdown used in analyses**. From this point continue with the analysis.

For more details, please see Chapter 5: Baseline Trend Analysis and Correction

[3] To add a **Barometric correction**, you must first enter or calculate the barometric efficiency (BE) of the aquifer. To do so, move to the **Pumping Test** tab and click on the button beside the **Bar. Eff.** field.

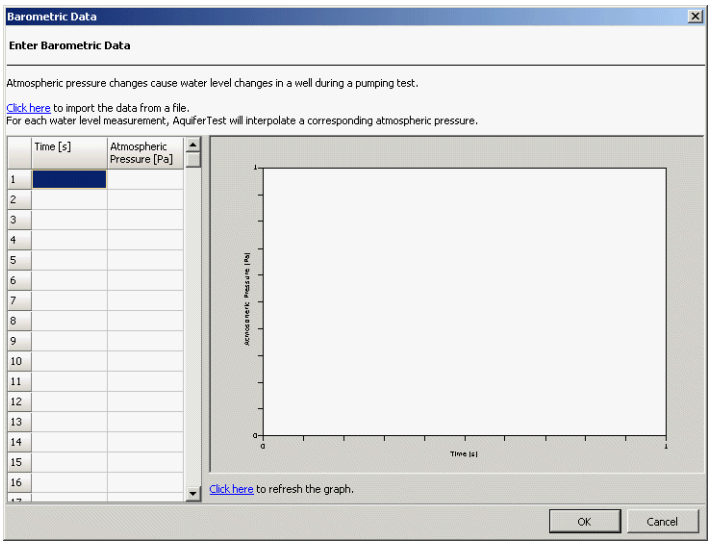


The following window will appear:


Calculate Barometric Efficiency (BE)
Calculation of the Barometric Efficiency (BE)
During a pumping test, atmospheric pressure changes may affect recorded water levels in a well. By calculating a barometric efficiency (BE) for the aquifer,the drawdown data can be corrected for this affect. The BE is defined as the ratio of change in water level in a well to the corresponding change in atmospheric pressure. The typical range is between 0.20 and 0.75.
Click here to import the data from a file.
Atmospheric Pressure
Water Level [m]
Barometric Efficiency: NAN
Click here to refresh the graph and update the results.
OK
Cancel

Manually enter data in the grid, or follow the **Click here** link above the table to import a pressure vs. water level data file. As the data is imported into the table, it is graphically displayed to the right of the table and the barometric efficiency is calculated and displayed below the graph. Click **[OK]** and the coefficient will appear in the **Bar. Eff.** field.

Return to the **Water Levels** tab, and select the appropriate well. From the **Add data correction** drop-down menu choose **Barometric correction** to produce the following dialog.


Barometric Data
Enter Barometric Data
Atmospheric pressure changes cause water level changes in a well during a pumping test.
Click here to import the data from a file.
For each water level measurement, AquiferTest will interpolate a corresponding atmospheric pressure.
Time [s]
Atmospheric Pressure [Pa]
Click here to refresh the graph.
OK
Cancel

Manually enter data in the grid, or follow the **Click here** link to the file that contains the time vs. pressure data that was collected at the same time as the drawdown data. As it is imported, the data will be presented graphically on the right. Click **[OK]** to apply the correction to the drawdown data and return to the **Water Levels** tab. You will see that there are two new columns - **Barometric correction** and **Corrected drawdown used in analyses**.

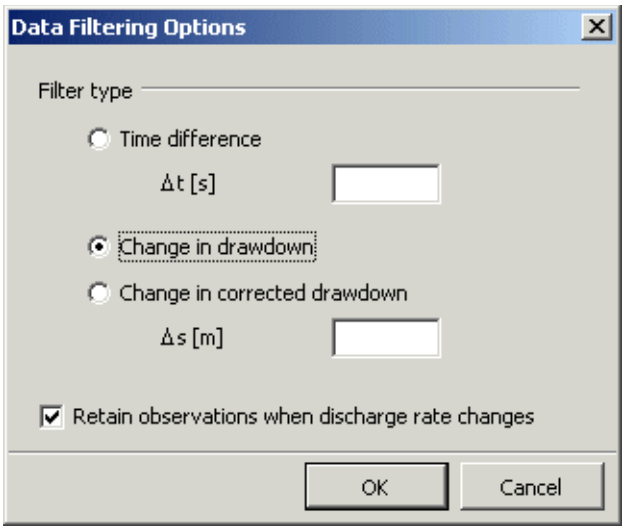
For more details, see Chapter 5: Barometric Trend Analysis and Correction.

Filter

The Filter check box is located to the right of the Data Correction menu and it allows you to reduce the number of data points in the dataset according to a specific criteria. There are two instances where filtering can be done in the program.

- While importing a data-logger file
- After manual data entry or importing a text/Excel file

Clicking on the Filter link will display the following dialog:



In this dialog, you can specify the parameters for filtering.

There are three ways to filter data:

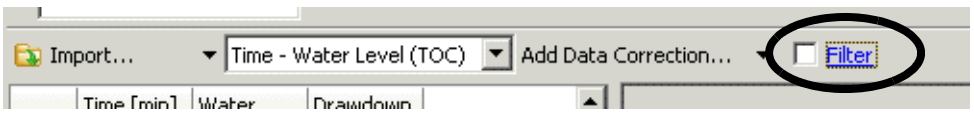
- By time difference
- By change in drawdown
- By change in drawdown after a trend, barometric, or user defined correction has been applied

To define a filter, select the desired filter option, and enter the criteria for that category.

Once the filter has been defined, click **[OK]** to return to the **Water Levels** tab.

After applying the filter, excluded data points will be temporarily hidden from the data table and the plot.

You can activate/deactivate the defined filter using the **Filter** check-box:



For more details on filtering during importing a data logger file, see “Import” on page 86.

Depth to Static Water level

Enter the depth to the water level before the test began, for either a pumping or slug test. This depth is subtracted from the Water Level measurements to obtain the **Drawdown** values.

NOTE: The static water level should be entered before you proceed to enter / import the time - water level data.

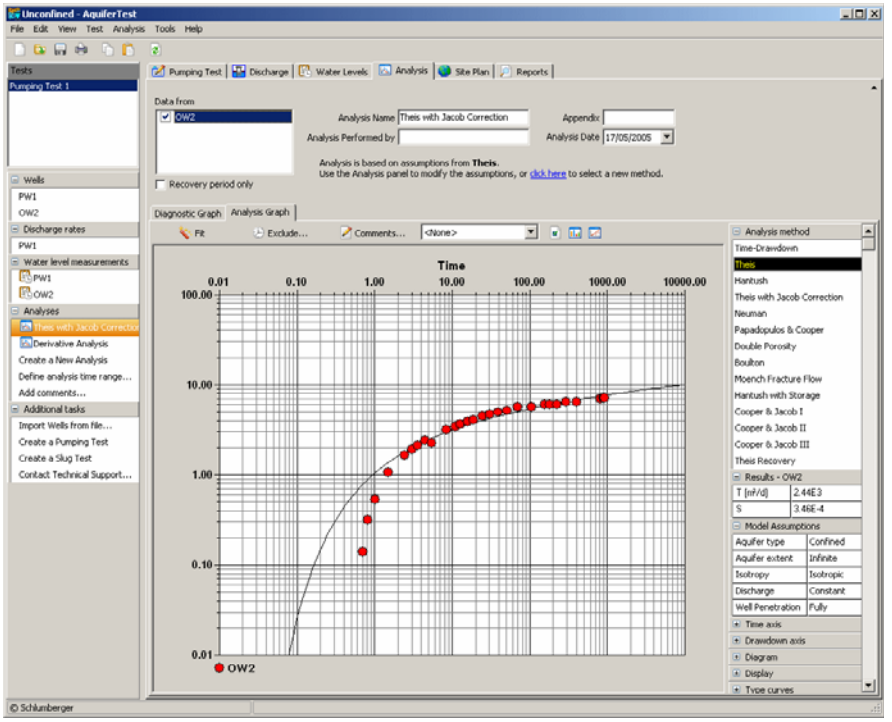
Water Level at t=0 (Slug tests only)

This field is located below Depth to static water level field and contains the water level at the start of the measuring period of the slug test - i.e. immediately after the slug has been inserted or removed.

This completes the Data Entry portion of the program. The next section describes the analysis of the data and report generation.

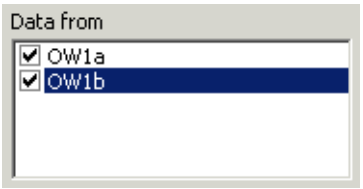
Analysis Tab

The **Analysis** tab is dynamic and contains different options depending on the type of test; however the general fields are the same. An example is shown below.

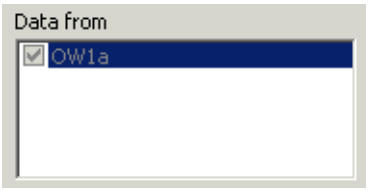


Data From

Select which wells to use for the analysis (pumping tests only). All wells that contain water level data will be listed in this window.



In a slug test there is only one test well and this well cannot be selected or unselected.



Analysis Name

Assign descriptive names to the analyses.

Date

Reflects the date for the test; by default, AquiferTest will use the date that the project was created. The pull-down calendar allows you to select a different date.

Analysis performed by

Allows you to enter the name of the analyst.

Recovery period only

This check box allows you to analyze only the data recorded after the pump was turned off. In this case, the recovery data will be analyzed using the Agarwal Recovery method. For more information on this analysis method, see Chapter 4: Recovery Analysis - Agarwal Solution (1980).

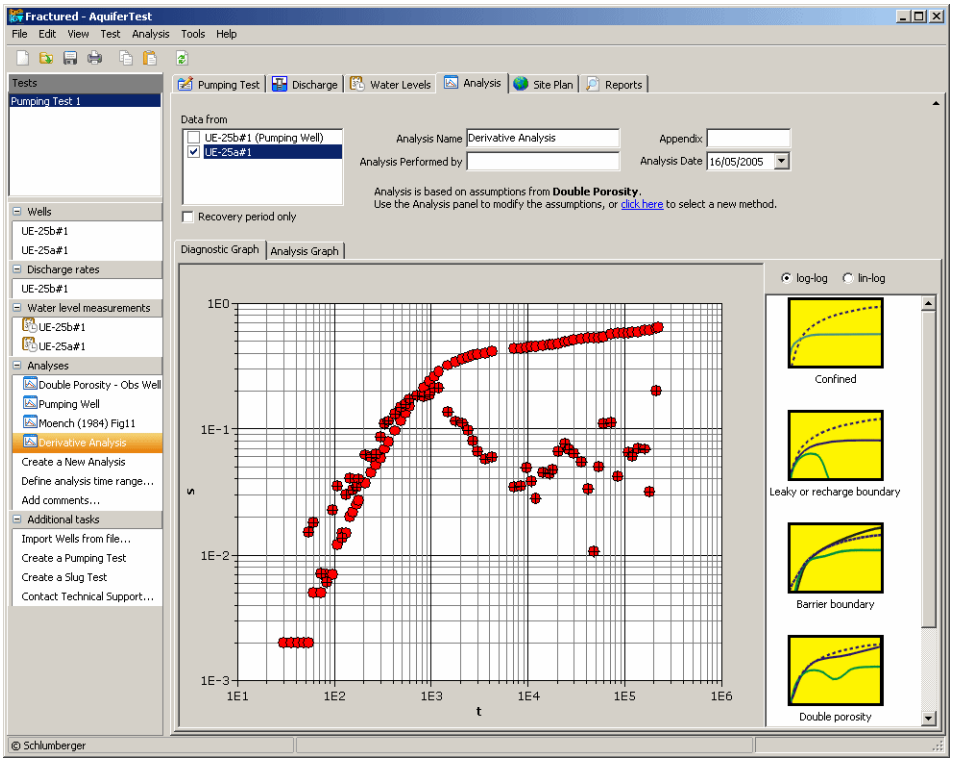
AquiferTest provides two graphing methods for the analysis: **Diagnostic Graph** and **Analysis Graph.**

Note: You can hide the general meta data fields (described above), i.e., Date, Analysis Name, Data From etc., to allow more screen space for the diagnostic and analysis

graphs. To do so, click the **Show/Hide** button located in the top-right corner of the **Analysis** tab.

Diagnostic Graph Tab

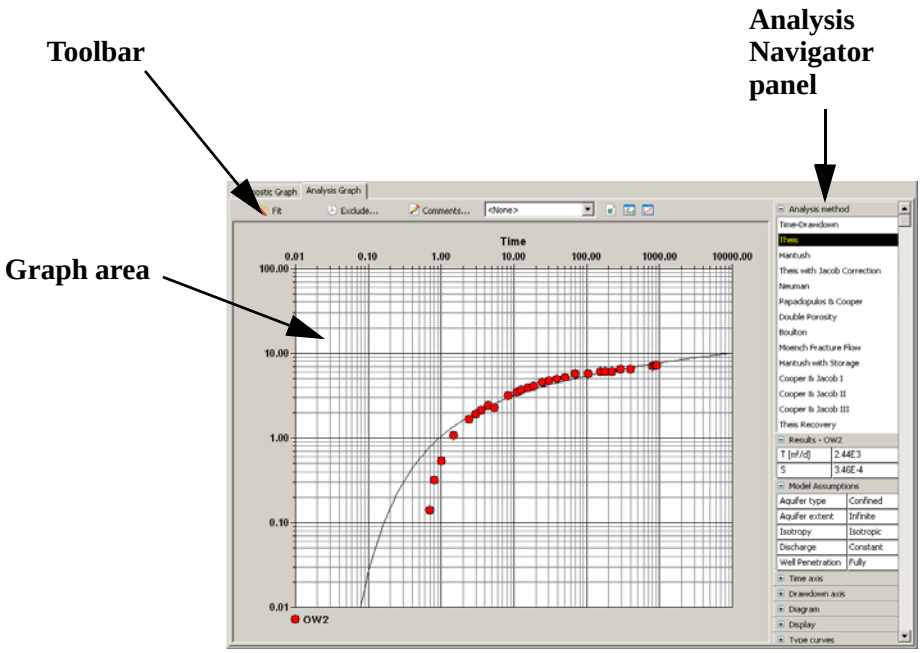
This tab allows you to view the data displayed in the log-log or semi-log graph. The right side contains the diagnostic graphs with theoretical drawdown curves for different aquifer conditions. Interpreting the data and the diagnostic graphs should help you identify the assumptions that should be made about the data and thus, to choose the appropriate analysis method.



The diagnostic graph displays the drawdown values on a log-log (or semi-log) scale, as well as the derivatives of those values. For more details, please see Chapter 4: Diagnostic Plots.

Analysis Graph Tab

The Analysis Graph tab consists of a tool bar, graph area, message window, and an Analysis Navigation panel.



Fit

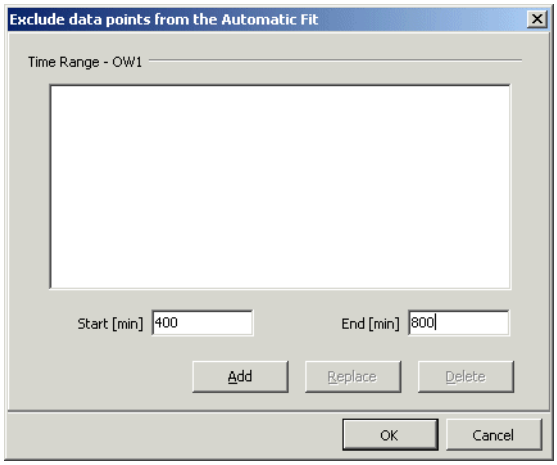
The

(Automatic Fit) button is the first in the tool bar; pressing this button will automatically fit the curve to your data set, and calculate the aquifer parameters. AquiferTest uses the “downhill simplex method” which is a minimizing algorithm for general non-linear functions. For more details, please see:

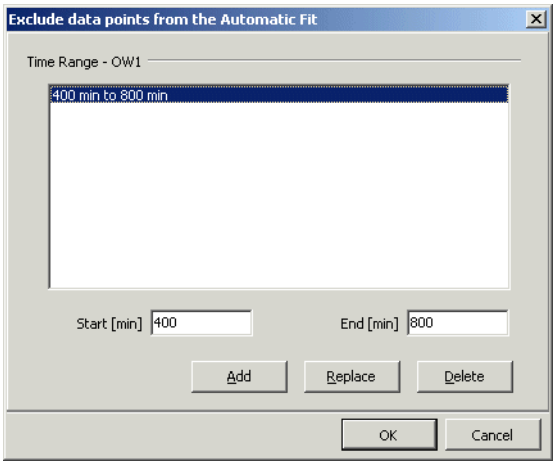
J.A. Nelder, R. Mead, A Simplex Method for Function Minimization, Computer Journal 7 (1965) 308.

Exclude

The **Exclude** button allows you to exclude datapoints based on a time range. When pressed, it will load the following dialog.



Enter the range of exclusion in the **Start** and **End** fields and press **Add**. The defined period will appear in the **Time Range** list.



Select the defined period and click **[OK]** to apply it. This will exclude data points between 400 and 800 minutes from analysis. They will still be displayed on the graph but will no longer be considered when the automatic fit is applied.

Comments

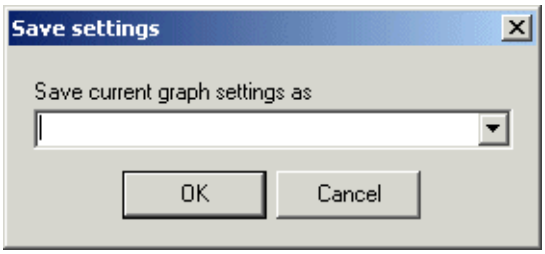
Click on the

(Comments) button, to load a dialog where you can record comments for the current analysis. You may alternately select **Add Comments...** from the Analysis frame of the **Project Navigator.**

Settings

The pull-down menu to the right of the **Comments...** button allows you to select from a list of graph settings. When **AquiferTest** is installed on your computer, there will be two default graph settings: Log-Log and Semi-Log. As you continue to use the software, you can save your settings using the (Save the graph settings as a template) icon.

The following dialog will appear where you can provide a unique name to your settings.



The new settings will now appear in the pull-down **Settings** combo box. To retrieve and apply settings for the current analysis graph, select a template from the list.

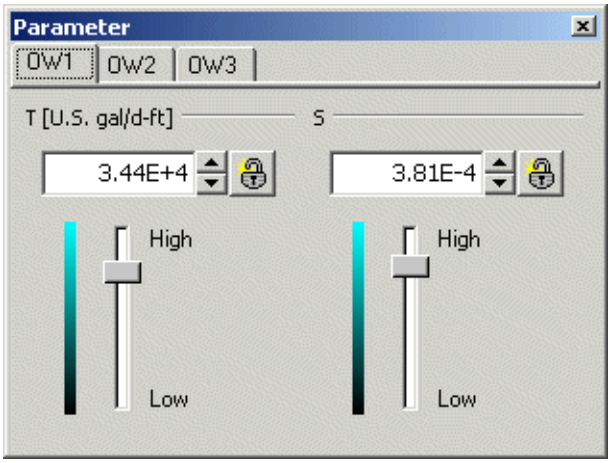
By using different graphical interpretations, you may be able to gain a better interpretation and analysis of a data set. For example, in comparing the Cooper Jacob to the Theis analysis, you can see that both methods generate similar results. As these are graphical methods of solution, there will often be a slight variation in the answers, depending upon the accuracy of the graph construction and subjective judgements in matching field data to type curves. (Fetter, 1994).

For an example of a semi-log straight line analysis (similar to the Cooper Jacob straight line method), see the example CooperJacob.HYT in the AquiferTest\Examples folder.

Parameter Controls

Click on the (Parameter controls) button to load a dialog where you can manually adjust the curve fit, and modify the Storativity, Transmissivity, Conductivity and other parameters that are displayed in the **Results** frame of the **Analysis Navigator** window. This feature allows you to apply your expertise and knowledge of the site conditions to obtain more accurate values for the above stated parameters.

Clicking on this icon will produce the following dialog box.



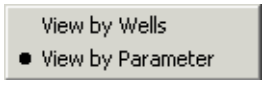
Parameters can be adjusted using the slider bars or the arrows beside the fields. The values can also be manually entered into the fields.

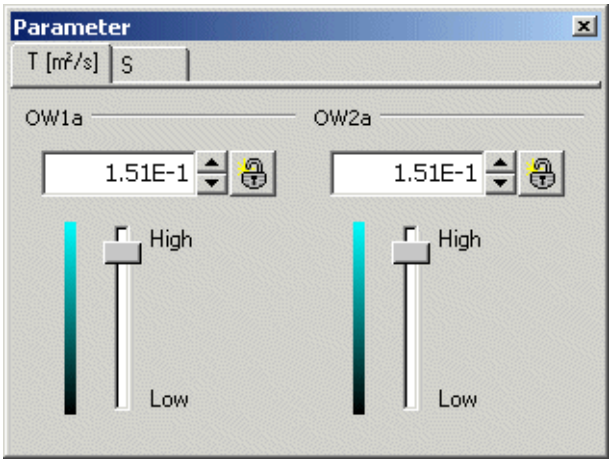
When the parameters are set to the desired values they can be locked for use in predictive analyses by pressing on the (Lock) icon beside the values.

The value becomes locked and the icon changes to .

When a parameter is locked, it will not be modified during an automatic fit. To unlock the parameter, simply click on the lock button again.

The tabs at the top of the window are used to switch between the wells. Right-clicking anywhere in the dialog will allow you to switch to a “View by Parameter” view of the dialog.





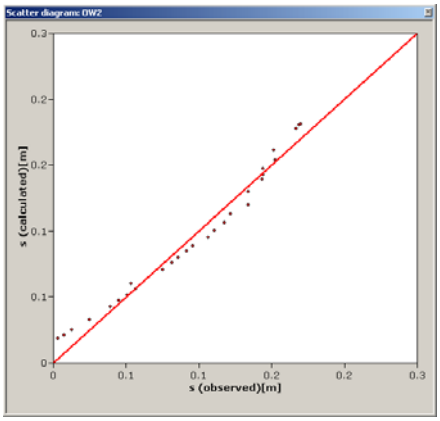
Now you can manipulate the parameter in both wells at the same time. The tabs at the top of the window are used to switch between parameters. This feature is useful is you wish to set a parameter to the same value in both wells.

Scatter Diagram

Click the **Scatter Diagram** button to load a scatter diagram of the current fit. The diagram plots the observed drawdown values (X-axis) against the calculated drawdown values (Y-axis), providing a visual representation of the quality of the fit. The 45 degree line colored red represents an ideal scenario, where the calculated values equal the observed values. However, this is not likely to happen in many real-life scenarios. If the data points appear above the line, then the calculated values are larger than the observed values, which may indicate that the model is over-predicting. If the data points are under the line, then the calculated values are less than the observed values, which may indicate that the model is under-predicting.

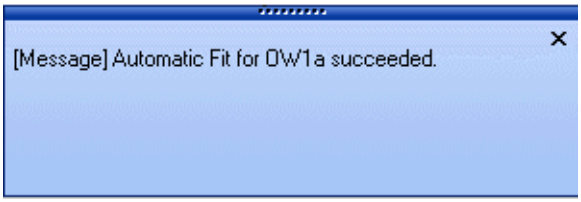
The scatter diagram can also be viewed in the statistics report, which can be accessed by selecting **Analysis / Statistics** from the main menu.

Note: The Scatter Diagram is only available for analysis methods with model functions, e.g., Theis, Hantush, etc. It is not available for the legacy methods (straight line methods), e.g., Cooper & Jacob, Hantush Bierschenk, Specific Capacity, Slug Tests, etc.



Message window

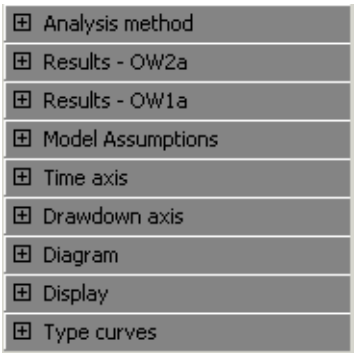
The message window displays all the messages, warnings, and error reports that occur while you conduct the data analysis. This message fades after five seconds.



Analysis Navigator panel

The **Analysis Navigator** panel is located to the right of the graph area. It contains all the functions that control the analysis of the selected data and the display on the screen. The **Analysis Navigator** contains following frames:

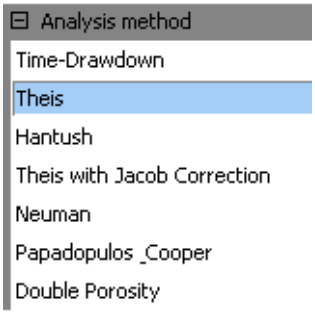
- Analysis method
- Results
- Model Assumptions (pumping test only)
- Time axis
- Drawdown axis
- Diagram
- Display
- Type curves



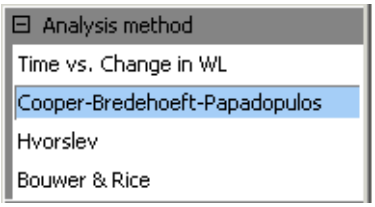
In the image above, all frames are shown collapsed. To view the contents of each frame, click on the “+” beside the name of the frame to expand it. In the following section, the components of each frame will be discussed.

Analysis method frame

- Pumping Tests



- Slug Tests



The analysis frame contains all analysis methods available for the current test. The available test methods differ for pumping tests and slug tests. To select a test method for the analysis, simply click on the analysis you wish to use, and it will become highlighted in blue. To learn more about the analysis methods available in **AquiferTest**, see Chapter 4: Theory and Analysis Methods.

Results

Results - OW1a	
T [m²/s]	9.12E-1
S	6.56E-2

In the **Analysis Panel**, there is one **Result** frame for every data set (observation well) in the test. The values listed in the **Results** frame vary depending on the analysis used. These values can be altered using **Parameter Controls** as described above.

Model Assumptions (Pumping Tests only)

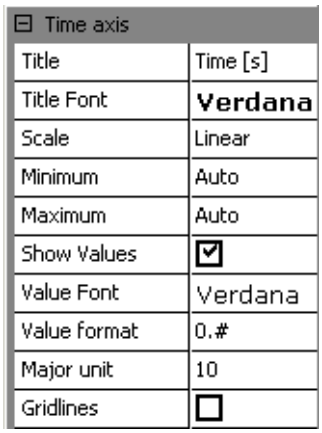
This frame lists the assumptions for the analysis you have chosen.

Model Assumptions	
Aquifer type	Confined
Aquifer extent	Infinite
Isotropy	Isotropic
Discharge	Constant
Well Penetration	Fully

These assumptions change depending on the selected analysis method, and can be altered based on the knowledge of the aquifer in question. For example, if you conducted a pumping test near a recharge boundary, start with a basic Theis analysis; if the data is characteristic of a boundary effects, then modify the “Aquifer Extent” assumption, and attempt a new curve fit. If the automatic fit fails, then attempt a manual curve fit using the parameter controls.

To change the assumption, click on the right portion of the assumption you wish to change, and select a new assumption from the list. The analysis view will refresh automatically. To learn more about analysis methods and their assumptions, see Chapter 4: Theory and Analysis Methods.

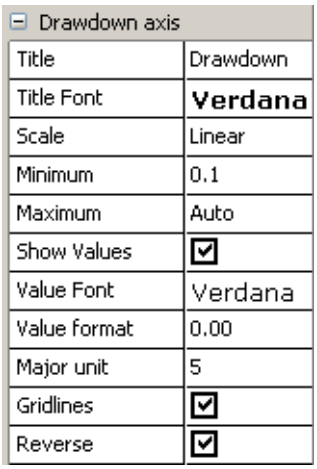
Time axis



Time axis frame specifies parameters for the horizontal axis of the analysis.

- Title - axis title that is displayed on the graph
- Title Font - the font for the axis title
- Scale - switch between linear and log scale. To switch, click on the right portion of the Scale line to produce a drop-down menu and choose the alternate system.
- Minimum - minimum value on the axis
- Maximum - maximum value on the axis
- Show Values - show/hide axis values
- Value Font - font for axis values
- Value format - specify the number of decimal places the axis values
- Major unit - number of divisions on the axis
- Gridlines - display vertical gridlines on the graph

Drawdown axis



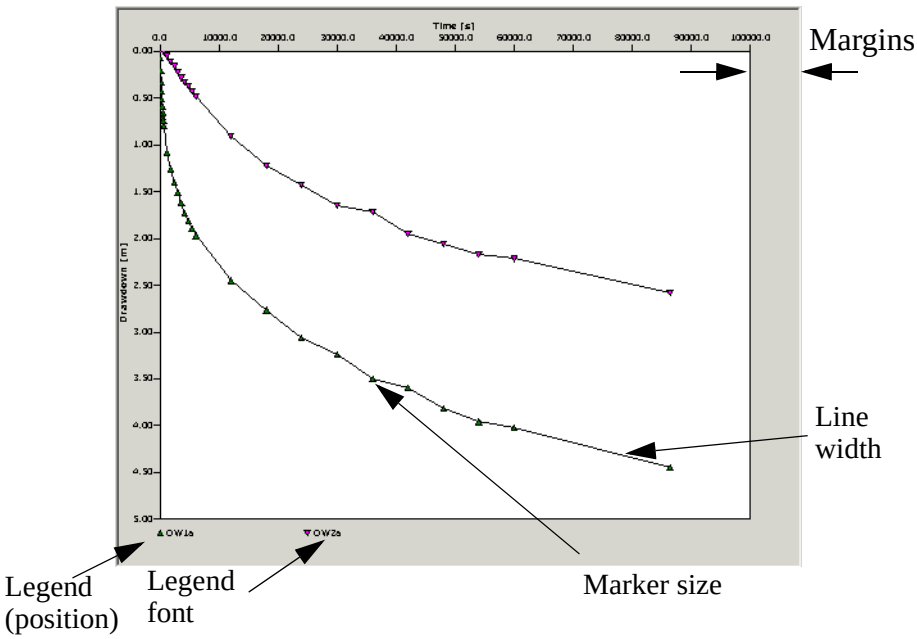
Drawdown axis frame specifies parameters for the vertical axis of the analysis.

- Title - axis title that is displayed on the graph
- Title Font - the font for the axis title
- Scale - switch between linear and log scale. To switch, click on the right portion of the Scale line to produce a drop-down menu and choose the alternate system.
- Minimum - minimum value on the axis
- Maximum - maximum value on the axis
- Show Values - show/hide axis values
- Value Font - font for axis values
- Value format - specify the number of decimal places the axis values
- Major unit - number of divisions on the axis
- Gridlines - display horizontal gridlines on the graph
- Reverse - set the origin (0,0) to the bottom-left corner or the top-left corner of the graph.

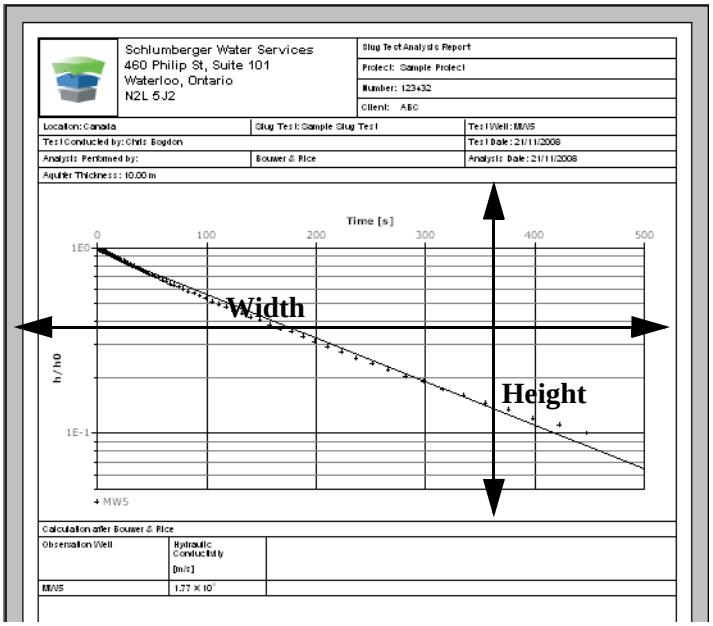
Diagram

Diagram	
Width [mm]	Auto
Height [mm]	Auto
Left margin [mm]	15
Upper margin [mm]	15
Right margin [mm]	10
Lower margin [mm]	10
Legend	None
Legend font	Ver...
Marker Size	7
Line width	3

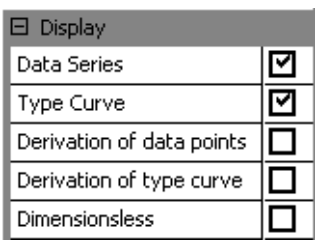
Diagram frame allows you to format the graph and the area immediately around it. The parameters in the frame control the following parameters in the graph area:



The graph width and height control the graph size.



Display



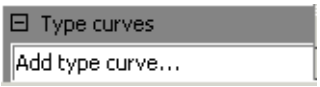
Display frame allows you to specify what information will be displayed on the graph.

- Data Series - show/hide time drawdown data points
- Type Curve - show/hide the type curve
- Derivation of data points - display the derivative of the time drawdown data points
- Derivation of type curve - display the derivative of the type curve
- Dimensionless - display dimensionless Drawdown vs. Time

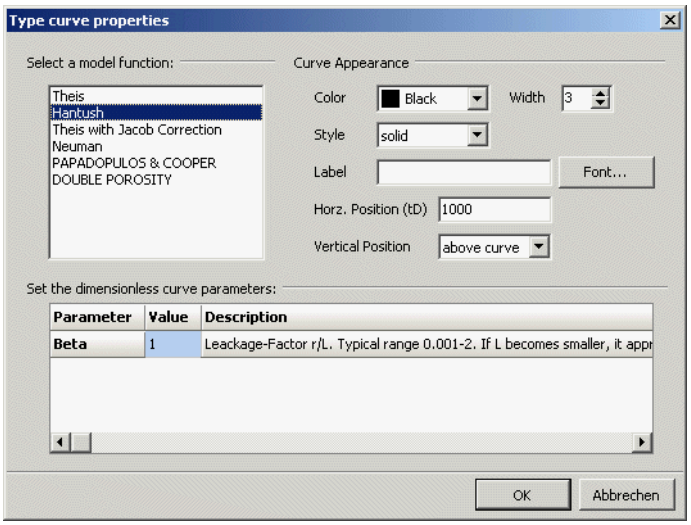
When data pre-processing is applied, another option, **Measured Data**, will be presented. This option allows you to display the original measured data along with the corrected.

The Display frame is dynamic, presenting the appropriate display options for different analysis methods.

Type curves



Allows you to overlay a type curve. Clicking on “Add type curve” will produce the following dialogue:



Select the type curve and specify the display parameters for that curve. For more details, see Chapter 4: Theory and Analysis Methods.

NOTE: You must have the “Dimensionless” mode active to see the added type curves.

This concludes the section on the Data Entry and Analysis windows. The next section will discuss the **Site Plan** tab.

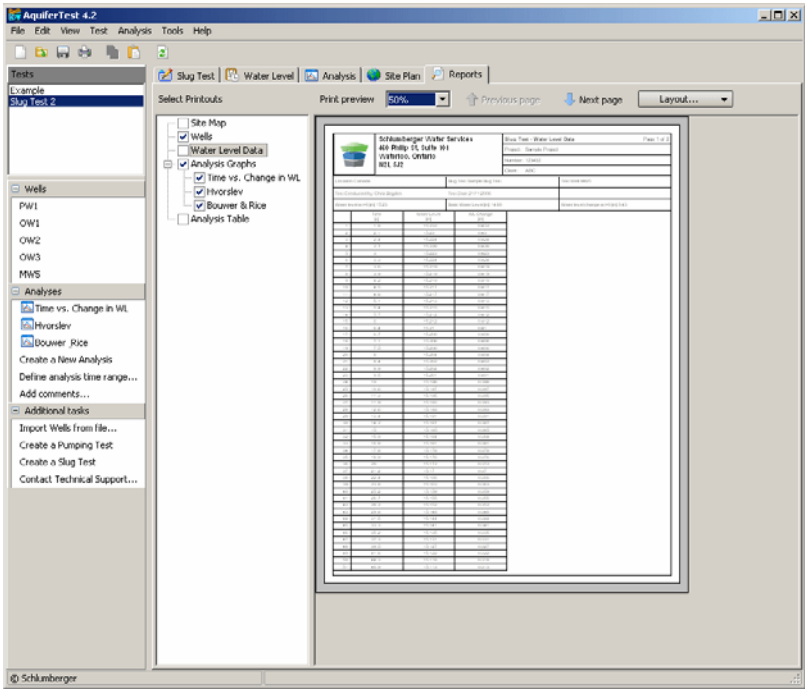
Site Plan Tab

The Site Plan tab allows you to load a map for the project, and optionally display contours of the drawdown data for your tests.

For information on how to use the Site Plan tab, please see Chapter 6: Mapping and Contouring.

Reports

The **Reports** tab allows you to customize the printed output of your project.



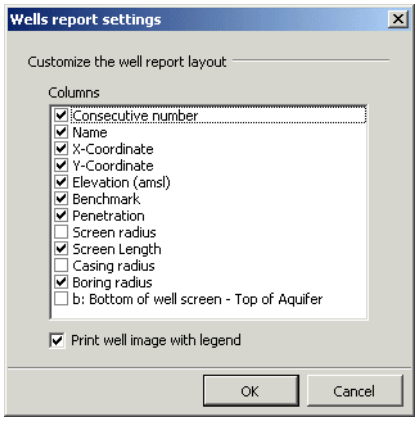
The individual reports templates are organized in the form of a tree where you can select one or more of the reports you wish to print.

You can scroll through multi-page report components (e.g. water level data report for hundreds of data points) using the **Next Page** / **Previous Page** buttons above the Preview window.

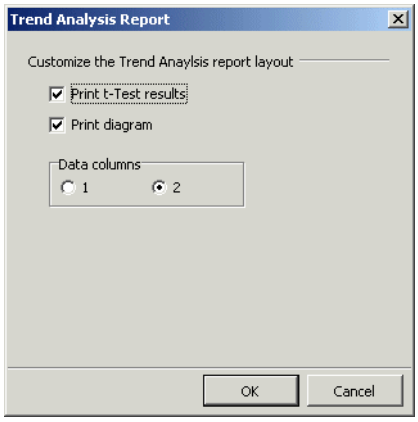
The company header and logo for the reports can be defined in the Options dialog, available under the Tools menu.

AquiferTest includes several pre-defined report templates; the report template structure cannot be modified; however, using the **Layout** drop-down menu (in the upper right corner), you can specify which components to show/hide in the various reports.

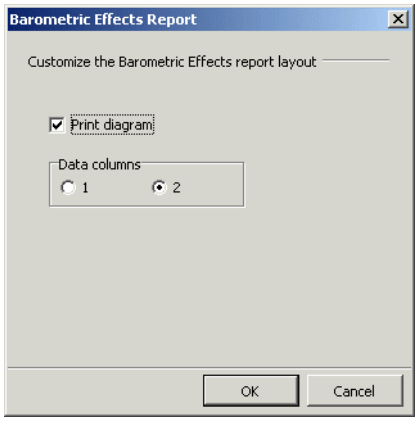
- **Layout/Wells** - specify what information you wish to be printed in the Wells report.



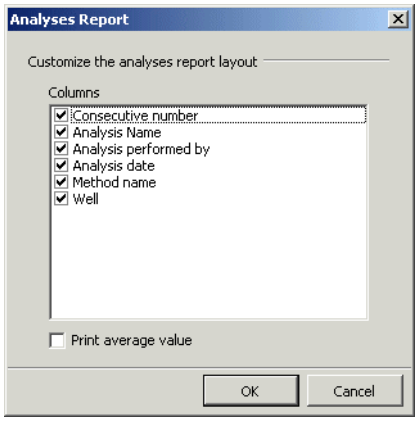
- **Layout/Trend Analysis** - specify what information you wish to be printed in the Trend Analysis report.



- **Layout/Barometric effects report** - specify what information you wish to be printed in the Barometric Effects report.



- **Layout/Analyses** - specify what information you wish to be printed in the Analysis report.



The **Report** tab is test specific, i.e. it offers the options to print components only for the currently selected pumping or slug test.

To print specific reports, place a check mark beside the desired report, and click the (**Print**) button, or select **File / Print** from main menu.

This concludes the description of the tabs. In the next section the main menu items will be discussed.

3.2 Main Menu Bar

3.2.1 File Menu

The **File** menu contains the following items:

New

Create a new project. To return to the existing project, select **Open Project**. AquiferTest projects are saved with the extension .HYT.

Open

Open an existing **AquiferTest** project. Recently opened projects appear at the bottom of the File Menu.

Close

Close the current project.

Save

Save the current project.

Save As

Save the current project as a new file name.

Import

The import menu contains several options. You can import one of the following:

- Well locations and geometry (from an .ASC, .TXT, .XLS or .SHP file)
- Site Maps
- Water Level data
- Data Logger File
- An **AquiferTest** version 3.X project database

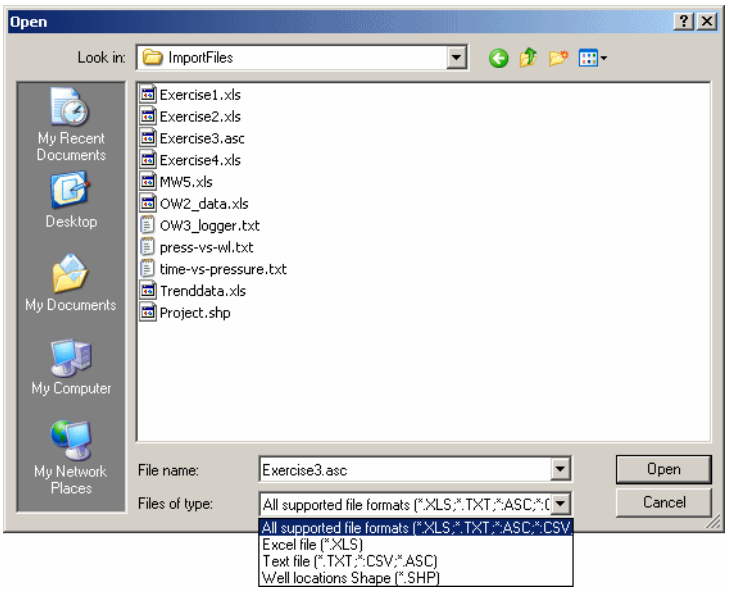
Importing Well Locations and Geometry

You can import well locations and geometry into your project from two locations:

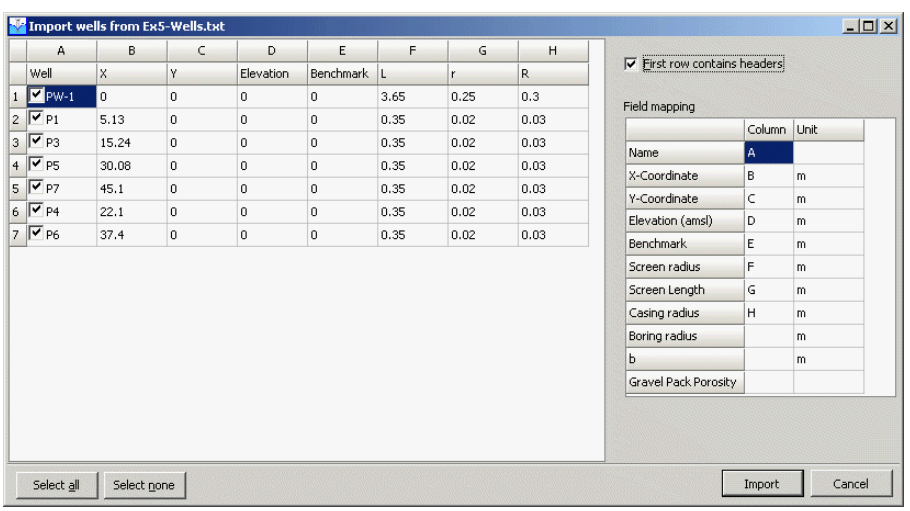
- **File/Import/Import Wells from file** menu option
- By right-clicking on the Wells grid and selecting **Import Wells from file**

- Selecting **Import wells from file** from the **Additional tasks** frame of the **Project Navigator**.

Using one of the methods listed above, the following dialogue is produced in which you can select the file (either .ASC, .TXT, .XLS or .SHP file) containing your well information:



Once selected, the **Wells Import** dialog will open as shown below.



The data to be imported falls into the following categories:

- Well name
- Well coordinates (X and Y)
- Elevation
- Benchmark elevation
- Well geometry (L, r, R, b, and Gravel Pack Porosity)

In the Wells Import dialog, match the data columns in the source file to the format required by **AquiferTest**.

The source file can be a Text file, Excel file or Shapefile, with one row allocated for each well.

[1] In the first column, select the wells you wish to import.

[2] The screen on the left shows the data set-up in the file. The **Field mapping** area on the right allows you to specify which columns in the file contain the data required by **AquiferTest**.

[3] If the first row in the data file contains names of the fields, check the box beside **First row contains headers**

[4] Click **[Import]** to complete the operation.

[5] Review the data in the Wells table to verify if the data was correctly imported.

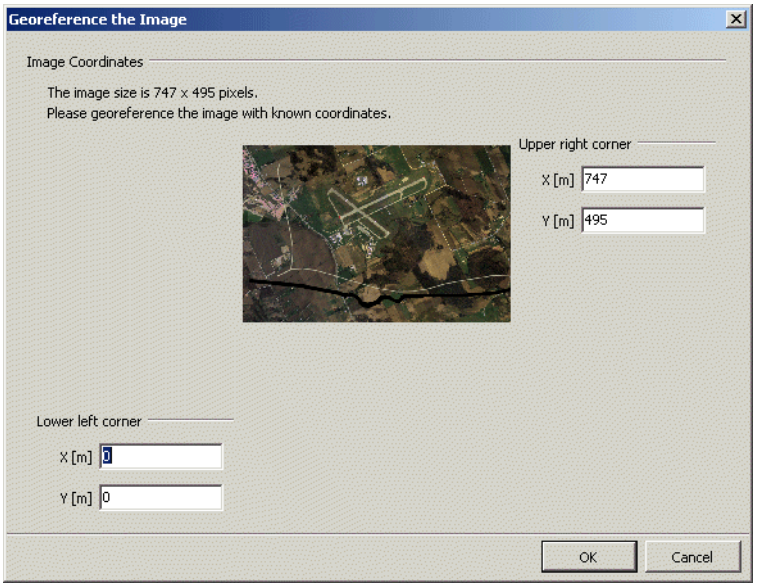
Import Map Image...

You can import a map image in two ways:

- **File/Import/Map Image...** menu option
- **Load** button in the Site Plan tab of the project

[1] Using one of the methods listed, a dialog will load, in which you can navigate to the appropriate file.

[2] Select the file, then click **[Open]** to produce the following dialogue:



AquiferTest will scan the image for the number of pixels in the image, and assign 1 length unit per pixel, in the X and Y axis, by default.

[3] To georeference the image, enter the coordinates for the map's bottom left and top right corner.

[4] Press **[OK]**

The map will be loaded in the **Site Plan** tab of the project. For more information on map options and well symbols, see Chapter 6: Mapping and Contouring.

Import Water Levels...

You can import water level data from an ASCII text file, or Excel spreadsheet, into your project from three locations:

- **File/Import/Water Level measurements...** menu option
- Clicking on the **Import** button in the **Water Levels** tab of the project
- Right clicking on the Water Level table and selecting **Import data**

[1] Using one of the methods listed, a dialog will load, in which you can navigate to the appropriate file.

[2] Select the file, then click **[Open]**

NOTE: Ensure that you are in the **Water Levels** tab and that the appropriate well is selected before importing water level data.

This procedure will copy the data into the **Water Level** table.

Text and Excel Import Format

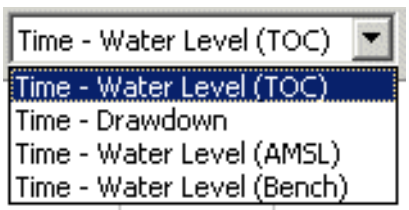
To import data from a file, it must be set up in a specific format. The source data must be in a text (.TXT) or MSExcel (.XLS) file, containing two columns of data.

The first column must be in column A (far left side of the page) and it must contain the elapsed time data.

The second column must be in column B (immediately adjacent to the time data, separated by Tab), and it must contain water level data. This may be in the format of depth to water level, drawdown, or water elevations (amsl or above a benchmark). An example is shown below.

	A	B	C
1	time (s)	Depth to WL (m)	
2	1.8	15.232	
3	2.1	15.230	
4	2.4	15.224	
5	2.7	15.228	
6	3	15.223	
7	3.3	15.224	
8	3.6	15.219	
9	3.9	15.219	
10	4.2	15.219	
11	4.5	15.217	
12	4.8	15.217	

NOTE: Be sure to select the water level coordinate system for the source file before importing (i.e. Time - Water Level (TOC) Time - Water Level (amsl), etc.) from the drop-down menu above the measurements window. For more information on the coordinate system see page 95.



The source file may contain a header in the first or second row; **AquiferTest** will ignore this during the import.

AquiferTest will not convert data from different units during the import. If the units in the source file are different from that defined in the current pumping/slug test, you can either change the units later, or ensure they are properly defined before importing.

Import Data Logger File

You can import a data logger file into your project from three locations:

- **File/Import/Data Logger File** menu option
- By selecting **Import Data Logger File** from the Import drop down menu in the **Water Levels** tab of the project
- Right-clicking on the Time/Water Levels table and selecting **Import Data Logger File...**

[1] Using one of the methods listed, a dialog will load in which you can navigate to the appropriate file.

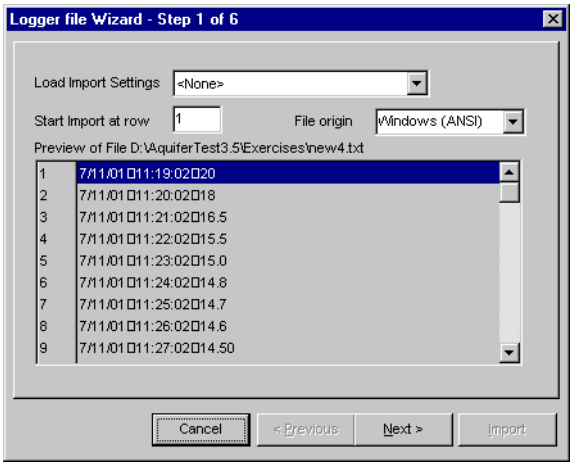
[2] Select the file, then click **[Open]** to launch the six-step data logger wizard described below.

AquiferTest supports the following formats:

- Generic Text (.TXT., .ASC)
- Level Logger (.LEV)
    - Level Logger: F-Series (Feet)
    - Level Logger: M-Series (Meters)
    - Level & Temperature Logger: F-Series (Feet)
    - Level & Temperature Logger: M-Series (Meters)
    - Level Loader (Feet)
    - Level Loader (Meters)
- Diver Datalogger (.MON):
    - Baro-Diver(14)
    - Cera-Diver(16)
    - CTD-Diver(ceramic)(12)
    - CTD-Diver(stainless steel(9)
    - Mini-Diver(14)
    - Micro-Diver(15)
    - (M)TD-Diver(10)
    - TD-Diver(07)

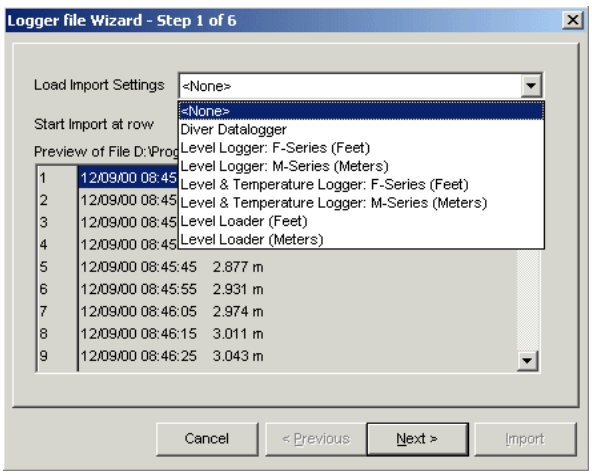
Logger File Wizard - Step 1

In the first step, specify the row number where you want to start importing. This is useful if there is header information in the logger file, that should be ignored.



At this step, you can also **Load Import Settings** saved from a previous import session. This eliminates the task of manually specifying individual settings at each step - a tremendous time-saver when importing multiple datalogger files of the same format.

If your data was recorded using a Level Logger or Diver datalogger, you have the option of selecting one of these pre-defined import settings:



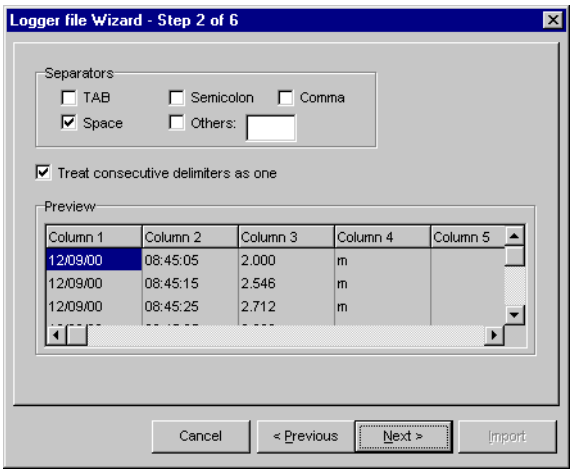
If you are using a Diver Datalogger or Level Logger, choose the correct model for your data logger. **AquiferTest** will then load the appropriate data settings for this logger file, including the starting row, delimiter, date format, and column locations. Simply press the **[Next>]** button to confirm that your file matches the pre-defined import settings in **AquiferTest**.

If you have previously saved your settings, locate them in the **Load Import Settings** drop-down menu. If there are no errors in the settings, the **Import** button will be

activated. Press the **Import** button to import the file. If there are errors, the **Import** button will not activate and you will need to determine the source of the error, by manually going through the six steps.

Logger File Wizard - Step 2

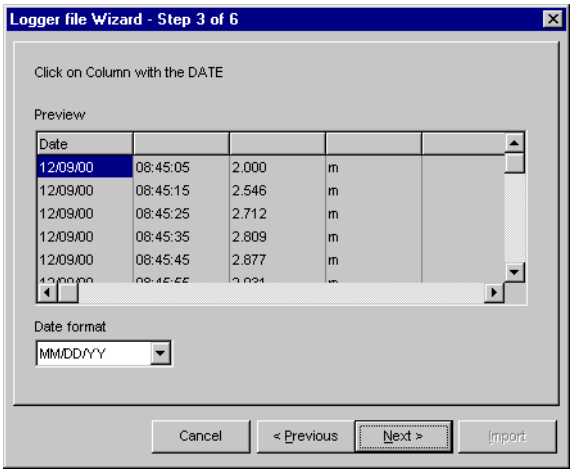
In the second step, specify the data delimiter. Knowledge of which data delimiter is used by your data logger is not required. Under **Separators**, simply click to choose the delimiter options until the data preview becomes separated into columns of date, time, and water level. The correct delimiter when chosen will separate the data columns automatically.



Logger File Wizard - Step 3

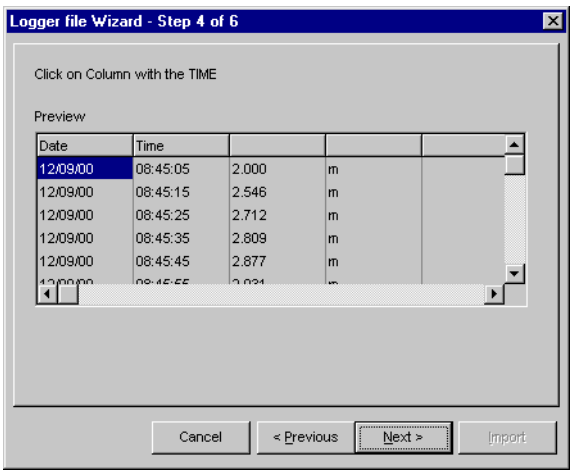
In the third step, click on the column header representing the **Date**. The word **Date** will appear in the column header title box. The **Date** format also needs to be selected; the Logger File Wizard supports the following formats:

- DD/MM/YY
- DD/MM/YYYY
- MM/DD/YY
- MM/DD/YYYY
- DD.MM.YY
- MM.DD.YY
- YYYY/MM/DD
- M/d/yyyy



Logger File Wizard - Step 4

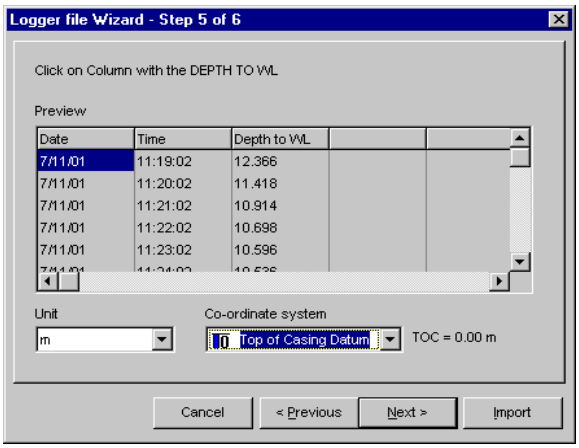
In the fourth step, click on the column header representing the **Time**. The word **Time** will appear in the column header title box.



Logger File Wizard - Step 5

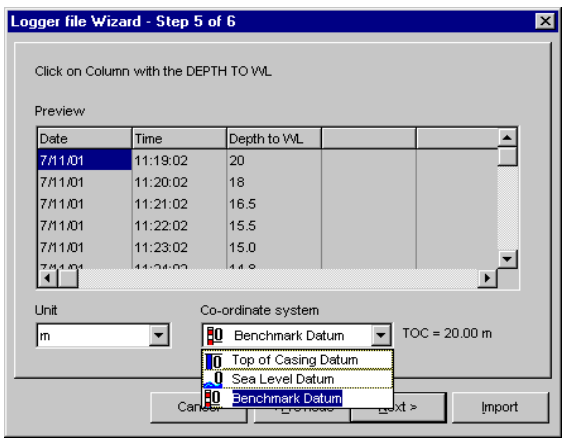
In the fifth step, click on the column header representing the **Depth to WL** data. The title **Depth to WL** will appear in the column header title box. The **Unit** for the water level data also needs to be selected; the Logger File Wizard supports the following formats:

- m
- cm
- mm
- inch
- ft
- yrd



Data will be converted to the units defined for the current test.

At the bottom of this window, specify the **Co-ordinate system** used during the data collection:



The default system is **Top of Casing Datum**; however if your data logger recorded data as water level elevation, then you have the option of importing the data in these formats as well.

- Using the **Top of Casing Datum**, the top of the casing (TOC) elevation is designated as zero, and the data will be imported as measurements from the top

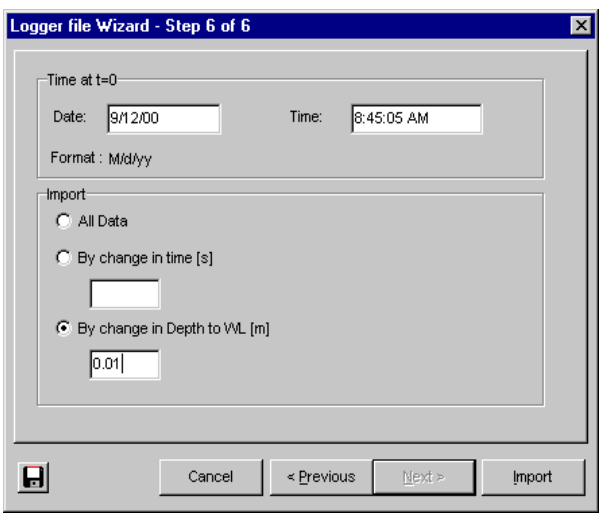
of the well casing to the water level (i.e. depth to water level, the traditional format). After you import/enter the data, you must enter a value for **Depth to static water level**. Then click on the **Refresh** icon and **AquiferTest** will make the appropriate drawdown calculations.

- Using the **Sea-Level Datum**, the top of casing (TOC) elevation is designated as the elevation (amsl) you have entered for that well. **AquiferTest** will read this elevation from the value you have input in the Wells section. **AquiferTest** will make the appropriate drawdown calculations by calculating the difference between the static water level elevation and the water levels recorded during the test.
- Using the **Benchmark Datum**, the top of casing (TOC) elevation is designated as the benchmark elevation you have entered for that well. **AquiferTest** will read this elevation from the value you have input in the Wells section. This elevation is relative to an arbitrary benchmark that would have been established during a site survey. As with the sea-level datum, **AquiferTest** will make the appropriate drawdown calculations by calculating the difference between the static water level elevation and the water levels recorded during the test.

NOTE: Please ensure that you have entered the necessary Well details (elevation (amsl) or the benchmark elevation) BEFORE you import/enter your data.

Logger File Wizard - Step 6

In the sixth step, specify which data values are imported. If the file contains many duplicate water levels (typical for a logger file), you may want to filter the data as shown below. You can filter the data by either change in time or change in water level.



The number of datapoints that can be imported by **AquiferTest** is limited by available system resources. However from a practical point of view, importing duplicate

datapoints is not useful in a conventional aquifer analysis. You should try to minimize the number of datapoints imported for each analysis as the performance decreases with increased data points. Applying one of the import filter options under **Import** will allow you to reduce the number of datapoints imported. You can also apply a filter after the data has been imported. See “Filter” on page 65 for more details.

Click on the **Save** icon in the lower-left corner, to save the settings that you have just used for the datalogger import:

Enter a name for the personalized settings, and click **[OK]** (My_Settings, for example). These settings can be recalled in the future and used for importing data sets in a similar format (see Logger File Wizard - Step 1).

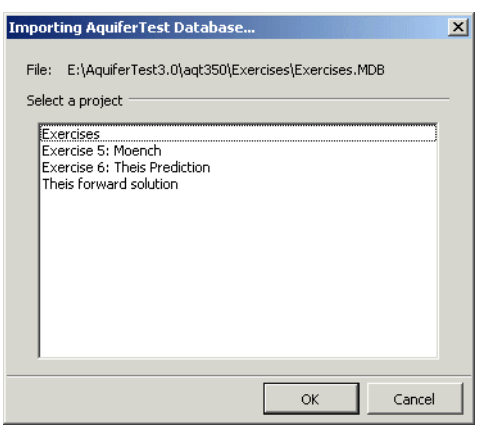
To finish the import process, click **[Import]** and the datapoints will be imported into your project.

Import AquiferTest 3.X Project...

To import a project from **AquiferTest v3.X**, from the main menu select **File/Import/ AquiferTest 3.x Database**.

[1] In the dialogue that appears, navigate to the database (.mdb) that contains the desired project.

[2] Double-click on the database or click **[Open]** after highlighting the database. The following dialogue will appear:



[3] Select the appropriate project and click **[OK]**

[4] The selected project will load into the active **AquiferTest** project window.

The imported project can then be saved in v.4.X format.

Print

There are two ways that you can send your report to the printer:

- Select **File/Print**
- Click the (Print) icon in the toolbar below the Main Menu.

Both options listed above will produce an output depending on which window is active in the project:

- Pumping (Slug) Test/Wells tab - prints the list of wells in the project accompanied by the coordinates and geometry
- Discharge - no output available
- Water Levels - print water levels for the currently active well
- Analysis - prints the current analysis graph and results
- Pumping (Slug) Test/Site Map tab - prints the current map view. This could include well locations, basemaps, and drawdown contours or color shaded map
- Report - in the **Report** tab you have the opportunity to select from desired report templates. To do so, expand the navigation tree in the left portion of the **Reports** tab and select which printouts you wish to obtain, and press **Print**.

NOTE: A print preview of any printable report can be obtained in the **Reports** tab by selecting the appropriate view from the navigator tree.

Print options are not available for Discharge plots or the plots in the Diagnostic Graphs tab. Use the copy feature (Edit / Copy from the main menu), then paste these images into a document or graphics editor.

Printer Setup

Selecting this option will load the dialogue to set-up your printer.

Exit

Exit the program. Ensure that you have saved the project before exiting.

3.2.2 Edit Menu

The **Edit** menu contains the following items:

Copy

Copy the selected item from **AquiferTest** to the Windows clipboard. Depending on your Windows System setup, the decimal sign used for the data will either be a period

(.) or a comma (,). You can change this within Windows by selecting **Start** > **Settings** > **Control Panel** > **Regional Options**.

Paste

Paste data from the Windows clipboard into **AquiferTest**. With this command, only the first two columns are transferred. Therefore, ensure that the first two columns of the information on the clipboard are the desired columns of data. When pasting data from a spreadsheet, the data must be in adjacent columns with the time data on the left and the water level data on the right. When pasting data from a text editor, the columns of data must be separated by tabs (tab delimited).

Delete

Delete an entry. Alternately, highlight the entry, then right-click and select **Delete** from the menu that appears. Entries include Time/Water level measurements and Well data. To delete a Test or an Analysis use the **Delete Object** option.

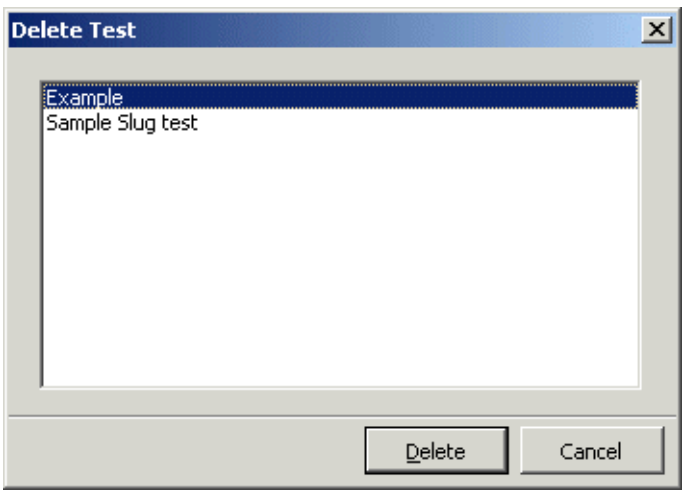
Delete Object

Delete objects such as analyses or tests.

Delete a Test

[1] Select **Edit/Delete Object/Test...**

[2] From the dialogue that has appears, choose the test you wish to delete:



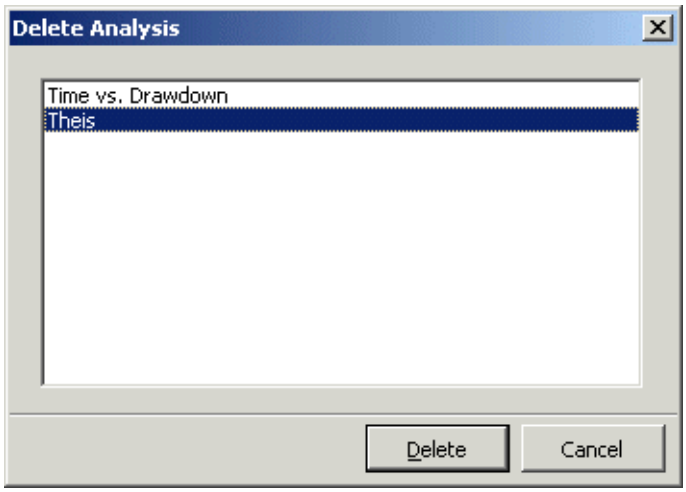
[3] Press **Delete**

Delete an Analysis

[1] Select the analysis to delete from the **Project Navigator**

[2] Select **Edit/Delete Object/Analysis...**

[3] From the dialogue that has appeared, choose the analysis you wish to delete



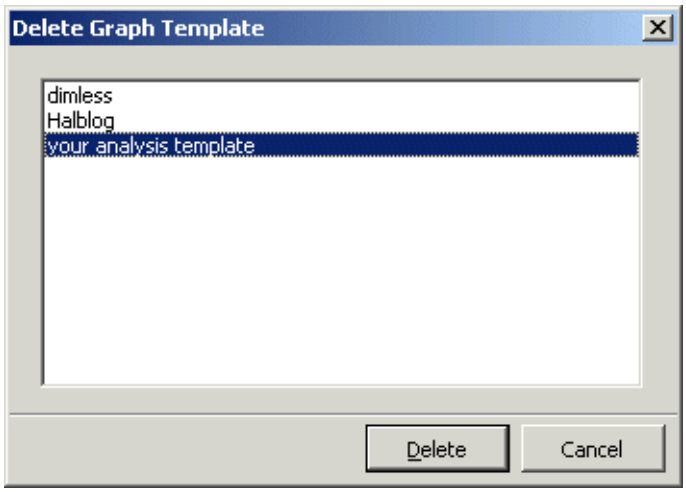
[4] Click **Delete**

Delete a Graph Template

On page 72 you learned how to save the graph settings you used for a particular analysis. To delete a graph settings template, follow the procedure below:

[1] Select **Edit/Delete Object/Graph Template...**

[2] From the dialogue that has appears, choose the template you wish to delete:



[3] Click **Delete**

NOTE: There is no undo function. Be sure that you select the appropriate object before deleting.

3.2.3 View Menu

The **View** menu contains the following items:

Navigation Panel

Show or hide the **Project Navigator**.

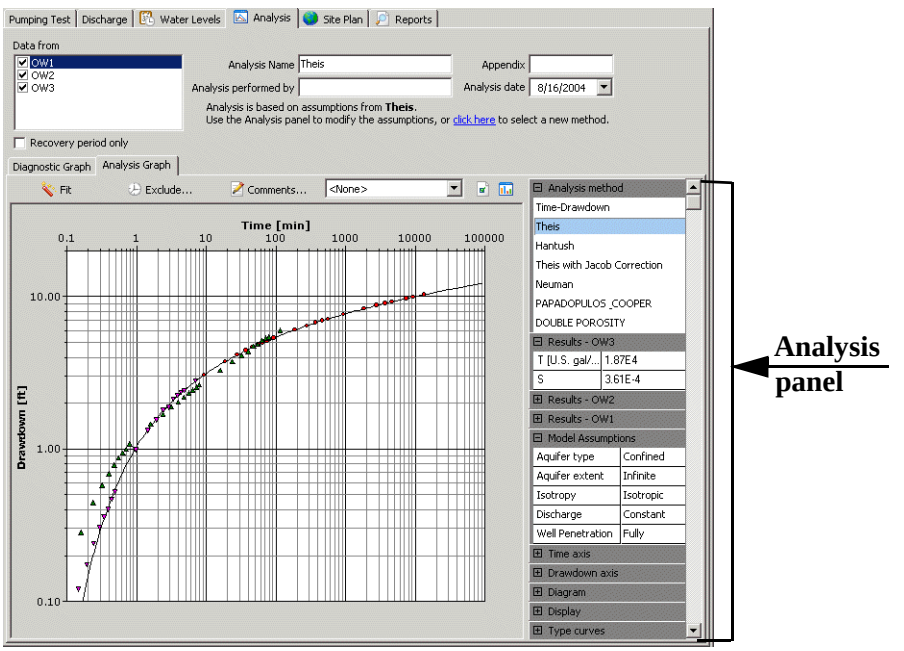
Button Labels

When this item is selected, a label is displayed under each toolbar icon.

When this option is not selected, the toolbar buttons are displayed under the menu bar without any labels. This saves space on the window.

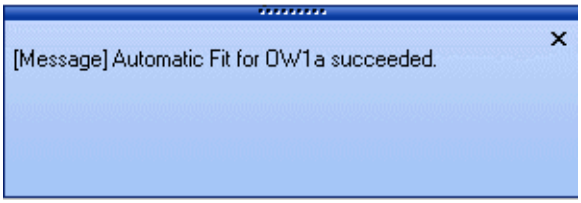
Analysis Panel

Show or hide the analysis panel. The analysis panel is visible when the Analysis tab is activated, and is located on the right side of the window.



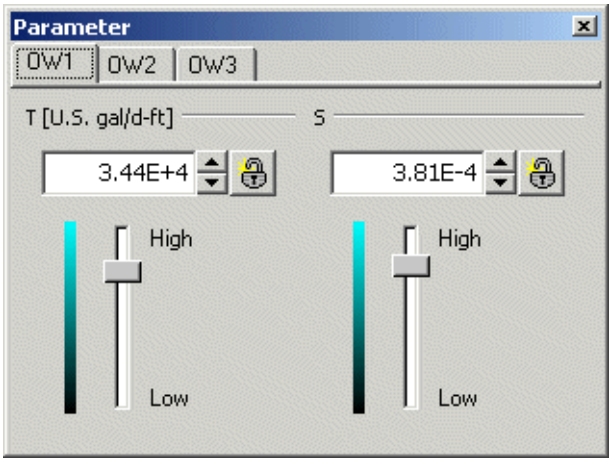
Analysis Status

Show the analysis status message box. The analysis status message box is visible when the Analysis tab is activated, and an Autofit is performed. The information may be advisory in nature, or may report the specifics of an error in the analysis. Errors are usually caused by the absence of required data for a chosen analysis.



Analysis Parameters

Show or hide the analysis parameter controls. These controls allow you to manually position the type curve, to your data.



Depending on the test you can adjust the values for different parameters to see how this affects the drawdown curve. Use the up and down arrow keys, or the slider bars, to adjust the values and see the resulting drawdown curve change in the graph below.

For more details, please see Chapter 4: Manual Curve Fitting.

Scatter Diagram

Show a scatter diagram of the current fit. For more information on the scatter diagram, please refer to “Scatter Diagram” on page 74.

3.2.4 Test Menu

The **Test** menu contains the following items:

Create a Pumping test

Selecting this menu option will create a new pumping test. Another way to create a pumping test is to select the link **Create a Pumping test** under the **Additional tasks** frame, in the **Project Navigator**.

When this is done, the Pumping Test tab will appear, and all fields will be blank (except the **Project Information** if you have already completed this in an earlier test).

In addition, any existing wells will be copied over to the new test, but will be set to "Not Used" by default.

In the **Pumping test** notebook page, you can enter the details of the pumping test including the Saturated Aquifer thickness, Units, and Wells. For more information see "Pumping Test Tab" on page 53.

The new pumping test will be saved in the existing **AquiferTest** project (.HYT file).

Create a Slug test

Selecting this menu option will create a new slug test. Another way to create a slug test is to select the link **Create a Slug test** under the **Additional tasks** frame, in the **Project Navigator**.

When this is done, the **Slug Test** tab will appear, and all fields will be blank (except the **Project Information** if you have already completed this in an earlier test).

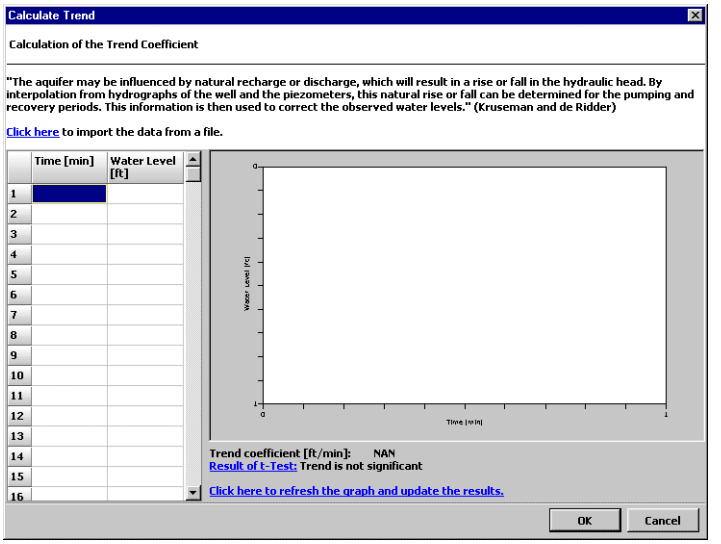
Any existing wells will be copied over to the new test, but will be set to "Not Used" by default.

For a slug test, only one well can be selected as the "Test Well". This is done in the well **Type** column, in the **Wells** grid (in the Slug Test tab). Create a new slug test for each additional test well.

For more information see "Slug Test Tab" on page 57

Trend Correction

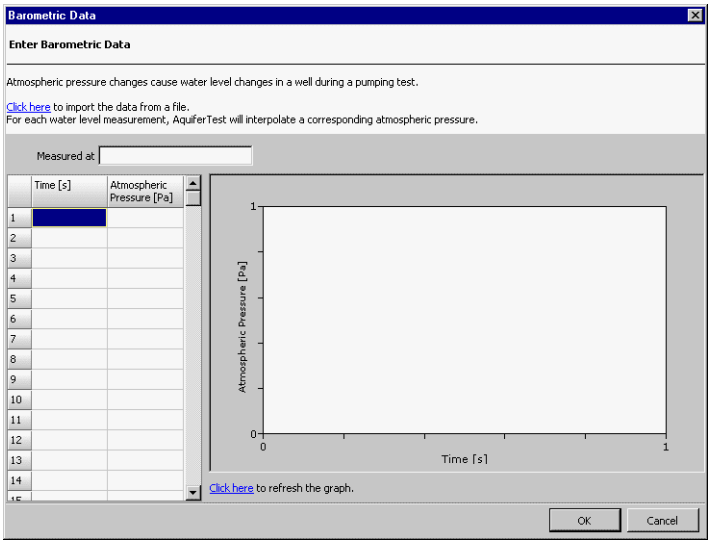
Load options for correcting water levels due to trend effects.


Calculate Trend
Calculation of the Trend Coefficient
"The aquifer may be influenced by natural recharge or discharge, which will result in a rise or fall in the hydraulic head. By interpolation from hydrographs of the well and the piezometers, this natural rise or fall can be determined for the pumping and recovery periods. This information is then used to correct the observed water levels." (Kruseman and de Ridder)
Click here to import the data from a file.
Time [min]
Water Level [ft]
Trend coefficient [ft/min]: NAN
Result of t-Test: Trend is not significant
Click here to refresh the graph and update the results.
OK
Cancel

For more details, please see Chapter 5: Data Pre-Processing

Barometric Correction

Load options for correcting water levels due to the influence of barometric effects.


Barometric Data
Enter Barometric Data
Atmospheric pressure changes cause water level changes in a well during a pumping test.
Click here to import the data from a file.
For each water level measurement, AquiferTest will interpolate a corresponding atmospheric pressure.
Measured at
Time [s]
Atmospheric Pressure [Pa]
Time [s]
Click here to refresh the graph.
OK
Cancel

For more details, please see Chapter 5: Data Pre-Processing.

3.2.5 Analysis Menu

The **Analysis** menu contains the following items:

Create Analysis

Create an analysis for the current pumping test. Another way to create an analysis is to select the **Create a New Analysis** link from the **Analyses** frame of the **Project Navigator**.

Depending on which test is selected, this function will create a new pumping test analysis or a new slug test analysis.

Create Analysis Considering Well Effects

Creates an analysis using the Papadopulos-Cooper method, which accounts for well-bore storage. For more details see Chapter 4: Theory and Analysis Methods.

Create Analysis for Specific Capacity

Creates a Specific Capacity analysis for the selected well. For more details, see Chapter 4: Specific Capacity.

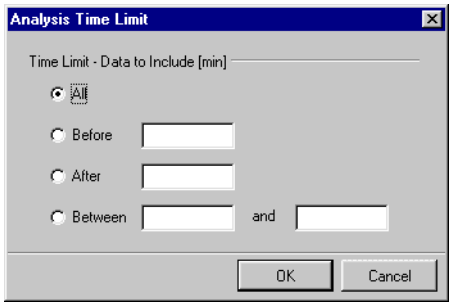
Well Losses

Creates a Hantush Biershenk analysis for the selected well. For more details, see Chapter 4: Hantush-Bierschenk Well Loss Solution

Define Analysis Time Range

Defines a time range of data points for the selected data set. Another way to perform this action is to select **Define analysis time range** from the **Analyses** frame of the **Project Navigator**.

Selecting this option will produce the following dialogue:



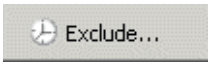
In this dialogue you can specify the time range for points that should be included. The excluded points will be removed completely from the analysis graph.

Fit

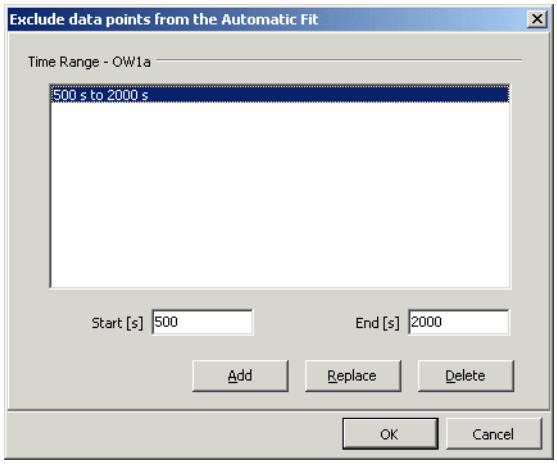
Performs an automatic fit for the selected well. Alternately, you may click the **Fit** button above the analysis graph.

Exclude

Allows you to exclude certain data points from the analysis. Alternately, you may click the **Exclude** button above the graph.



In the window that appears, define the time limit ranges that should be excluded.



NOTE: The excluded points will remain on the graph, but will be excluded from the Automatic fit. To temporarily hide data points from the graph, use the **Define analysis**

time range option which allows you to limit the data **Before**, **After**, or **Between** specified time(s).

Comments

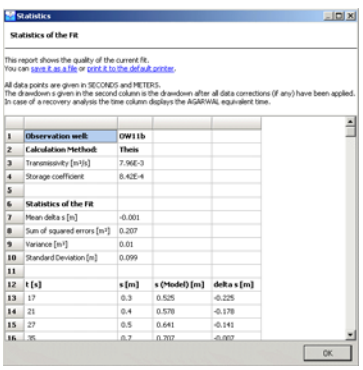
Allows you to add comments to the active analysis. Alternately, click the **Comments** button.

In the window that appears enter any comments. These will appear when the Analysis report is printed.

Statistics

Allows you to view statistics for the selected analysis, and current selected well. This option may also be loaded by *right*-clicking on the Analysis graph, and selecting **Statistics**.

The following Statistics window will appear.


Statistics
Statistics of the FIT
This report shows the quality of the current fit.
You can save it as a file or print it to the default printer.
All data points are given in SECONDS and METERS.
The drawdown s given in the second column is the drawdown after all data corrections (if any) have been applied.
In case of a recovery analysis the time column displays the AGARWAL equivalent time.
1 Observation well: OW11b
2 Calculation Method: Theis
3 Transmissivity [m²/s] 7.96E-3
4 Storage coefficient 8.42E-4
5
6 Statistics of the FIT
7 Mean delta s [m] -0.001
8 Sum of squared errors [m²] 0.207
9 Variance [m²] 0.01
10 Standard Deviation [m] 0.099
11
12 t [s] s [m] s (*Model) [m] delta s [m]
13 17 0.3 0.525 -0.225
14 21 0.4 0.578 -0.178
15 27 0.5 0.641 -0.141
16 35 0.7 0.707 -0.007
OK

The summary report contains statistics for the automatic fit, as well as the delta S between the observed drawdown, and the drawdown value on the modeled curve. A scatter diagram is displayed at the bottom of the window, providing a visual representation of the quality of the current fit.

NOTE: All data is converted to time in seconds, and length in meters.

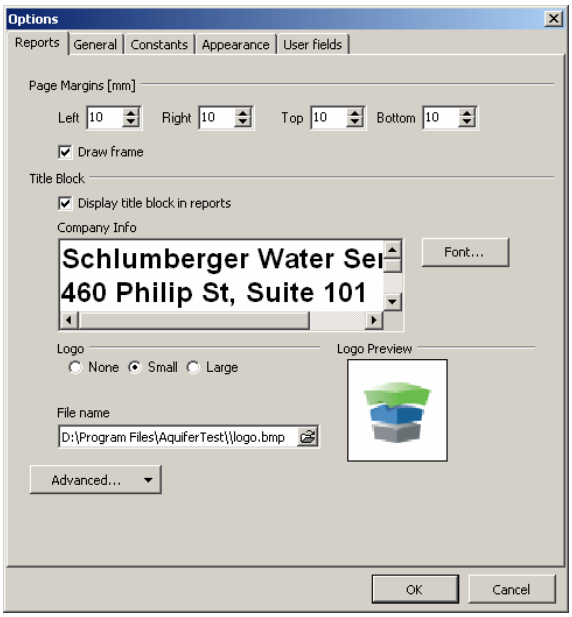
The statistics summary may be printed as is, or exported to .TXT or .XLS format.

3.2.6 Tools Menu

Options

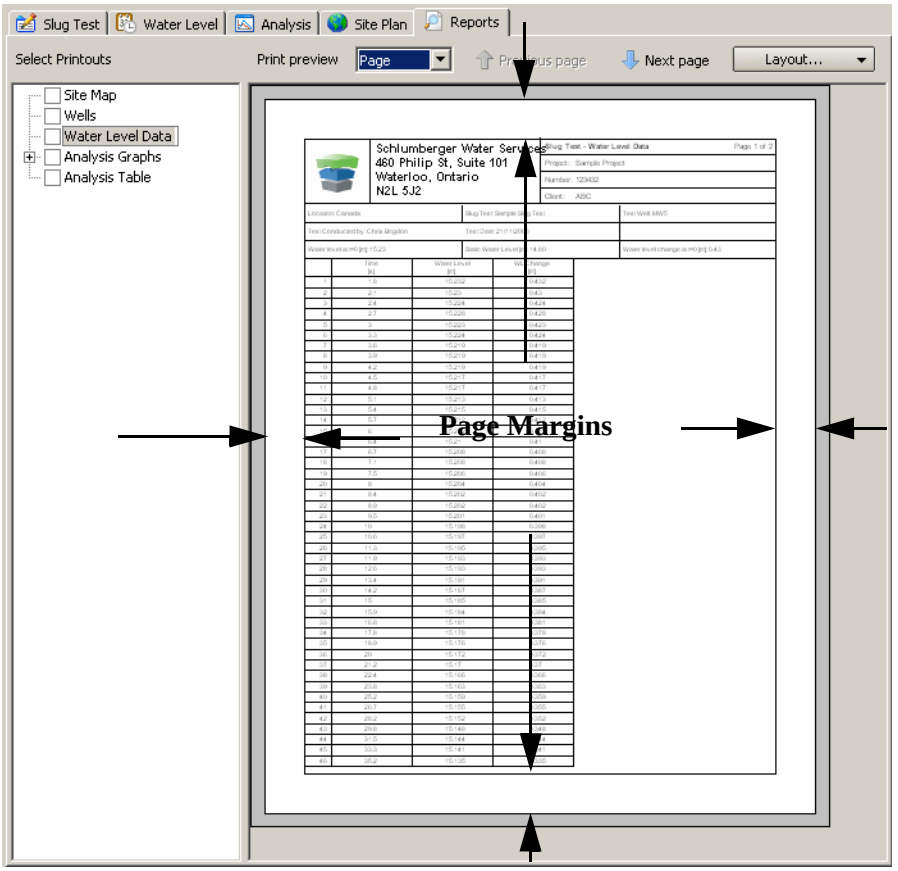
Specify settings for various program options.

Reports tab



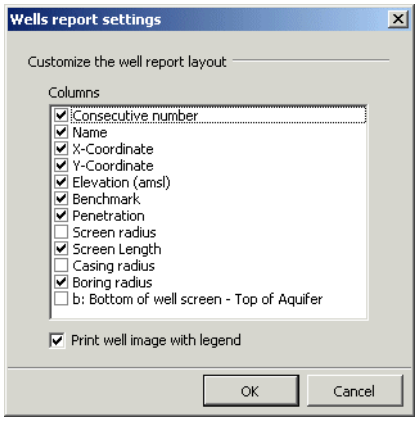
This tab allows you to format the report printouts.

- **Page Margins** - set Left, Right, Top, and Bottom margins

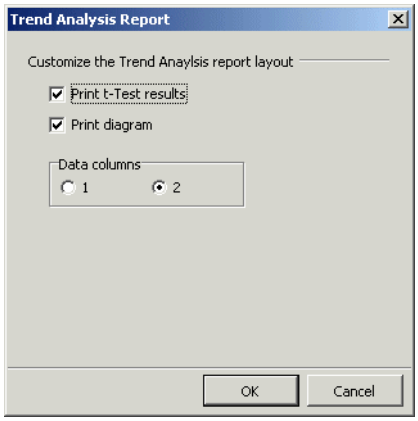


- **Title Block** - set up your company title the way you wish it to appear on reports. You have the option of disabling the title block so that it doesn't print on every page of the report. Change the font and size of the title by clicking on the **Font** button.
- **Logo/Logo Preview** - define a logo that will be printed with the company info. Specify the image file that contains the logo and choose the size in which it will be displayed. Image files supported by **AquiferTest** include bitmap (.BMP), icon (.ICO), metafile (.WMF), and enhanced metafile (.EMF). Generally your graphic should have a length-to-height ratio of 1:1. If your logo appears on the screen but not on printed reports, your printer may not be set up for Windows operation. If this occurs, ask your network administrator for technical assistance.

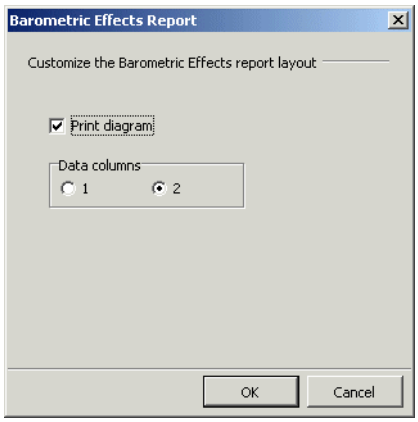
- **Advanced/Wells** - produces a dialogue that allows you to specify what information you wish to be printed in the Wells report.



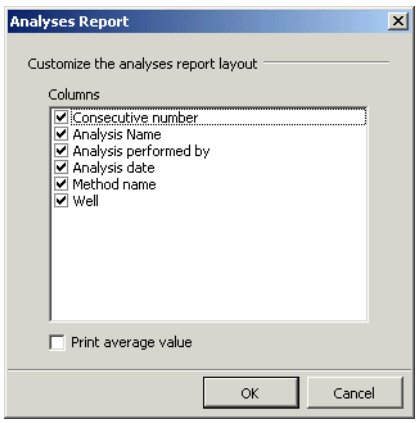
- **Advanced/Trend Analysis** - produces a dialogue that allows you to specify what information you wish to be printed in the Trend Analysis report.



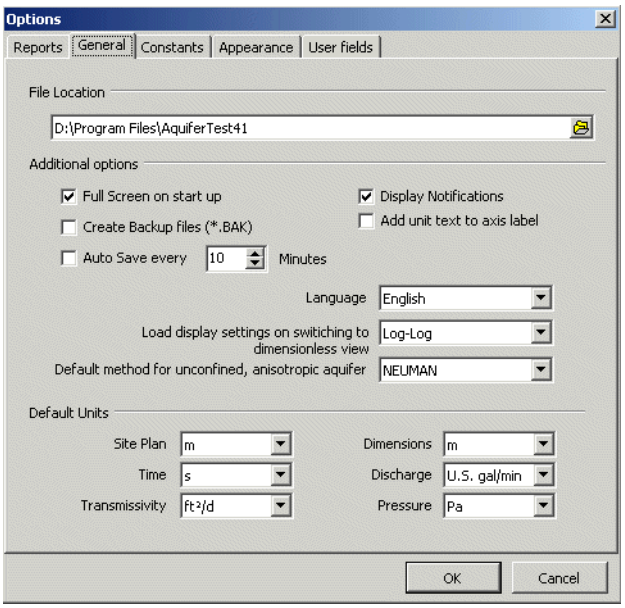
- **Advanced/Barometric effects report** - produces a dialogue that allows you to specify what information you wish to be printed in the Barometric Effects report.



- **Advanced/Analyses** - produces a dialogue that allows you to specify what information you wish to be printed in the Analysis report.



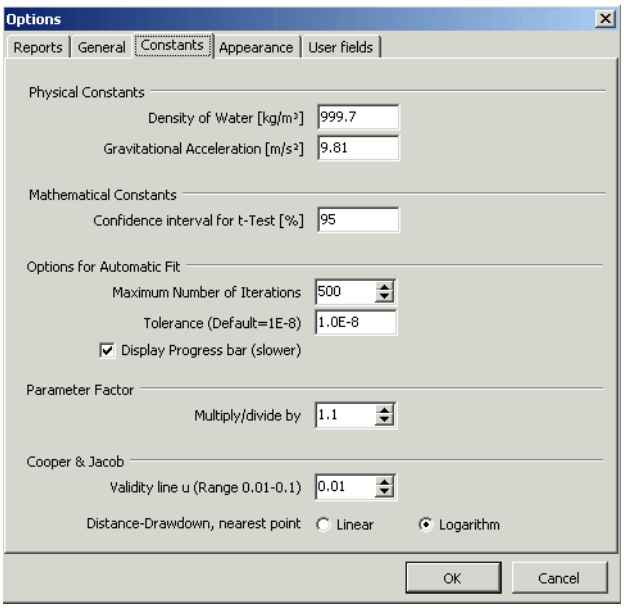
General Tab



Contains general program settings such as:

- **File location** - specify default folder for saving/opening projects
- **Additional options**
  - Load the program as full screen
  - Display notifications (warning messages) in the Analysis tab
  - Create back-up files of your project with extension .BAK
  - Enable the Autosave feature and specify the time interval
  - Set the display language
  - Select a graph template to be used when you switch to “Dimensionless” view
  - Default method for unconfined, anisotropic aquifer analysis: Choose between Neuman or Boulton. The selected analysis method will be used by default, whenever unconfined, anisotropic is set for the model assumptions
- **Default Units:** set the units that are loaded with each newly created test

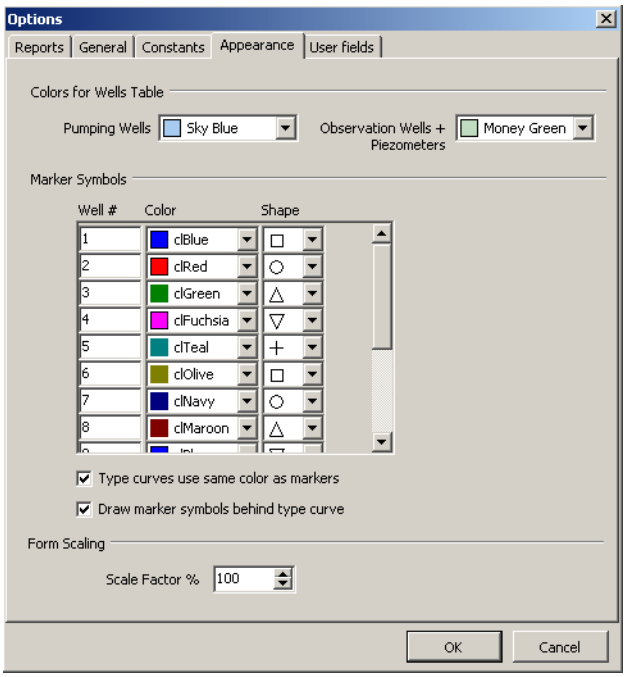
Constants tab



Define the physical and mathematical constants that **AquiferTest** uses for different computations.

- The **density of water** and **acceleration due to gravity** are used e.g. in the barometric pressure correction calculations
- The **confidence interval of the t-test** is used in the trend correction.
- **Automatic fit**: specify the maximum number of iterations, to be used during the automatic fit, and display a progress bar in the **Analysis** graph window. Higher iterations will result in slower processing times.
- **Parameter Factor**: Set a factor for adjusting parameter values; this is used in the Analysis Parameter controls, when doing the manual adjustment of the curve fit and aquifer parameters. The default interval value is 1.5.
- **Cooper Jacob**:
  - Set a value for u for the validity line. Value must be between 0.01 and 0.1
  - Select the option for determining closest point, for the Cooper Jacob Distance Drawdown analysis. When using this method, you are required to enter a time value for the analysis. If there is no observed water level for this time value, AquiferTest will search for the next closest observation point, back and forward in time. Assume you are looking for the closest point for t = 100 s and you have data points at 10 s and 300 s. If Linear is selected the program takes the data point at 10 s, because delta t is 90 s (compared to the other point, where delta t is 200 s). If Log is selected the program uses the 300 s data point, because ABS (log(300) – log(100)) is 0.477, compared to ABS (log(10)-log(100)) which is 1.

Appearance tab



Colors for Wells Table

Specify the colors to differentiate between the pumping and observation wells.

Marker Symbols

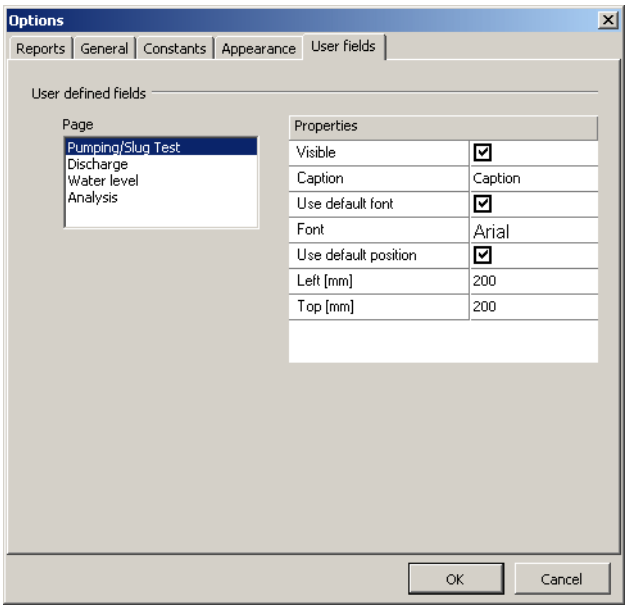
In this form you can also customize the appearance of the symbols which are used to represent the wells on the site map and analysis graphs. Use the combo-boxes to select the color and shape of the symbol. The symbols are assigned to the wells based on the order in which they were created.

If the **Type curves use same color as markers** check box is selected, all type curves will be colored the same color as the markers. If the **Draw marker symbols behind type curve** option is selected, the marker symbols will always appear behind the type curves.

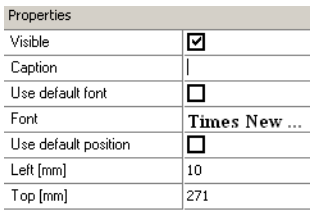
Form Scaling

The **Form Scaling** option allows you to set a scaling factor for the main form. This is helpful when using large fonts for your display, or having other problems with displaying labels on the AquiferTest forms. It scales up/down so all controls can be seen and accessed.

User fields tab



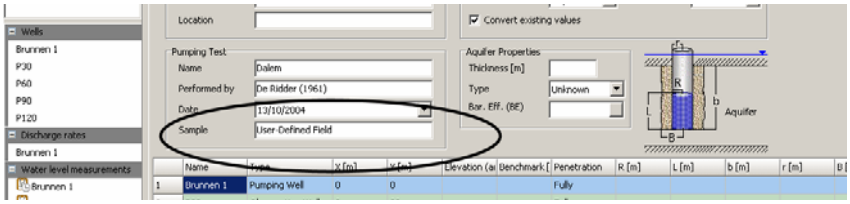
AquiferTest allows you to create up to four user-defined fields, for displaying in project reports. A text field can be added to any of the following project tabs: *Pumping/Slug Test*, *Discharge*, *Water Level* and *Analysis*. Use this tab to specify the properties for each user-defined field.



The field properties include:

Visible Enable/Disable user-defined field. Selecting this option will add the field to its respective tab. Deselecting this option will remove the field from its respective tab.

For example, when the user-defined field for the Pumping/Slug Test tab is enabled, it will appear below the date field under the Pumping/Slug Test tab, as shown in the image below.



Caption Specify a caption for the field, e.g.,“Sample” in the image above.

Use default font Select to show the field on the report using the default report font

Font If **Use default font** is unchecked, specify a customized font style for the field text

Use default position Select to position the field on the report in its default position. Deselect this option, and use **Left [mm]** and **Top[mm]** to define a different position on the report page.

Left [mm] Define a position along the Y-axis

Top [mm] Define a position along the X-Axis

Note: Page coordinates values are expressed relative to the upper-left corner of the page (0,0).

If the **Use default position** option is disabled, you can also drag and drop the field anywhere on the report, as desired.

3.2.7 Help Menu

The **Help** menu contains links to assist you, should problems arise while you are working with **AquiferTest**.

Contents...

Opens the table of contents of the on-line help file. The help file is identical to the printed user’s manual, however it contains cross-referenced links that allow you to find information quicker.

Tutorial...

Loads the Tutorial instructions. The “Learning by Doing” tutorial will guide you through most of the major functions of **AquiferTest** and is designed to highlight the program’s capabilities.

About...

Displays license, version, and copyright information for **AquiferTest** and how to contact us.

4

Theory and Analysis Methods

AquiferTest is used to analyze data gathered from pumping tests and slug tests. Solution methods available in **AquiferTest** cover the full range of aquifer settings: unconfined, confined, leaky, and fractured.

The full theoretical background of each solution method is beyond the scope of this manual. However, a summary of each solution method, including limitations and applications, is included in this chapter. This information is presented to help you select the correct solution method for your specific aquifer settings.

Additional information can be obtained from hydrogeology texts such as:

- Freeze, R.A. and J.A. Cherry, 1979. Groundwater, Prentice-Hall, Inc. Englewood Cliffs, New Jersey 07632, 604 p.
- Kruseman, G.P. and N.A. de Ridder, 1990. Analysis and Evaluation of Pumping Test Data Second Edition (Completely Revised) ILRI publication 47. Intern. Inst. for Land Reclamation and Improvements, Wageningen, Netherlands, 377 p.
- Fetter, C.W., 1994. Applied Hydrogeology, Third Edition, Prentice-Hall, Inc., Upper Saddle River, New Jersey, 691 p.
- Dominico, P.A. and F.W. Schwartz, 1990. Physical and Chemical Hydrogeology. John Wiley & Sons, Inc. 824 p.
- Driscoll, F. G., 1987. Groundwater and Wells, Johnson Division, St. Paul, Minnesota 55112, 1089 p.

In addition, several key publications are cited in the References section at the end of this chapter.

4.1 Background

The methodology of **AquiferTest** is very different from its predecessors. In earlier versions, you would select the most suitable analysis method for the data, based on the assumptions and data requirements, and obtain the results. In **AquiferTest**, the approach is somewhat reversed. Now, you specify the model assumptions (aquifer type, isotropy, boundary conditions, discharge type, and well penetration), and **AquiferTest** attempts to select the most suitable solution method.

In addition, some of the methods from **v. 3.5** have been replaced. For example, in **AquiferTest v.3.5 Pro**, the Theis method was implemented in five formats:

- Classical Theis solution: with the assumption of isotropic, infinitely extending confined aquifer, and constant pumping rate
- Theis Prediction, same assumptions as classical Theis solution, however no drawdown data was necessary
- Theis Forward: similar assumptions, however using superposition, could also support multiple pumping wells, variable pumping rates, and correction for partially penetrating pumping wells
- Stallman Forward, Recharge Boundary: Theis method, with the addition of a correction factor for a recharge boundary
- Stallman Forward, Barrier Boundary: Theis method, with the addition of a correction factor for a negative (barrier) boundary condition.

The abundance of solution methods led to some ambiguity and vagueness concerning the assumptions and limitations of an individual method. In **AquiferTest**, there is a single Theis method; by changing the model assumptions, you can replicate any of the aforementioned scenarios.

The process in **AquiferTest** is systematic, and as such, easier to understand. By explicitly indicating the known aquifer type and/or conditions, (which can be determined using the diagnostic plots), you know which effects are considered in the selected solution method.

Generally, it is recommended that you start with a simple model, and gradually increase the complexity. That is, for a pumping test, start with the default Theis set of assumptions, and change them only if you observe phenomena that do not fit this model. For example, if you know that the aquifer is bounded 400 m away, you could initially change the assumptions from “infinite” to “barrier bounded”, however this would not be the correct approach. It takes some time until the depression cone reaches that barrier, and you might miss other important effects in the meantime.

To summarize, **AquiferTest** allows you to calculate aquifer parameters in all the possible scenarios that were available in previous versions; the difference is that instead of using explicitly defined solution names (Stallman, etc), the results are obtained by starting with a standard solution, and sequentially applying correction factors in order to get to the most suitable solution.

4.2 Graphing Options

4.2.1 Diagnostic Plots

Calculating hydraulic characteristics would be relatively easy if the aquifer system (i.e. aquifer plus well) were precisely known. This is generally not the case, so interpreting a pumping test is primarily a matter of identifying an unknown system. System identification relies on models, the characteristics of which are assumed to represent the characteristics of the real aquifer system (Kruseman and de Ridder, 1990).

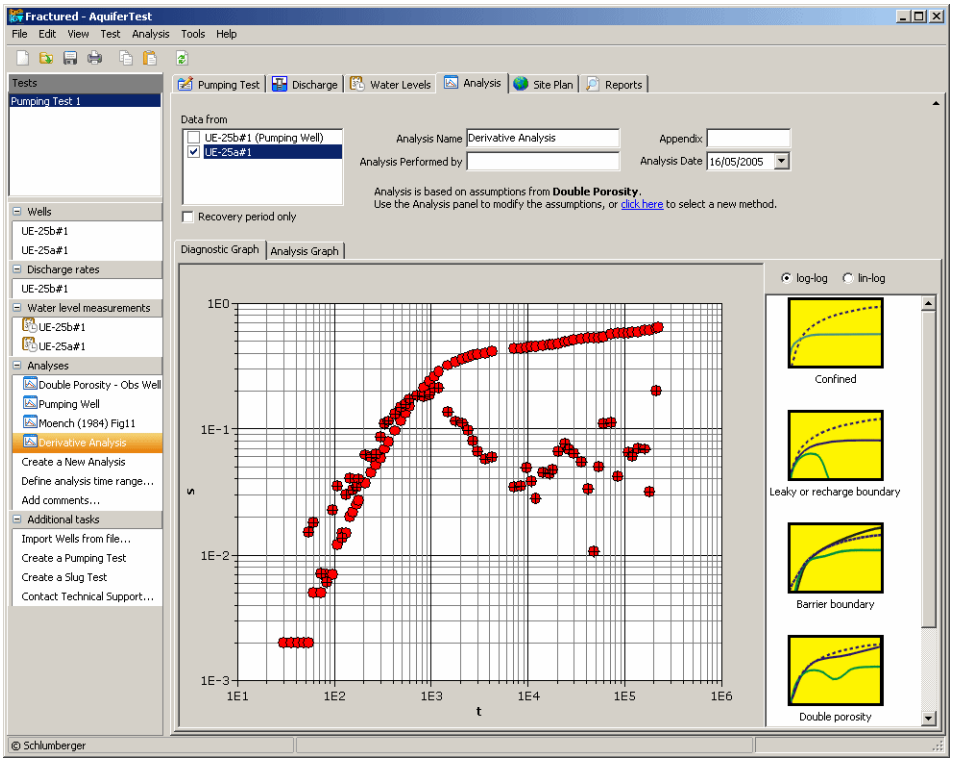
In a pumping test the type of aquifer, the well effects (well losses and well bore storage, and partial penetration), and the boundary conditions (barrier or recharge boundaries) dominate at different times during the test. They affect the drawdown behavior of the system in their own individual ways. So, to identify an aquifer system, one must compare its drawdown behavior with that of the various theoretical models. The model that compares best with the real system is then selected for the calculation of the hydraulic parameters (Kruseman and de Ridder, 1990).

AquiferTest now includes the tools to help you to determine the aquifer type and conditions before conducting the analysis. In **AquiferTest**, the various theoretical models are referred to as **Diagnostic plots**. **Diagnostic plots** are plots of drawdown vs. the time since pumping began; these plots are available in log-log or semi-log format. The diagnostic plots allow the dominating flow regimes to be identified; these yield straight lines on specialized plots. The characteristic shape of the curves can help in selecting the appropriate solution method (Kruseman and de Ridder, 1990).

In addition, the **Diagnostic plots** also display the theoretical drawdown derivative curves (i.e. the rate of change of drawdown over time). Quite often, the derivative data can prove to be more meaningful for choosing the appropriate solution method.

NOTE: Diagnostic Graphs are available for Pumping Tests only.

To view the **Diagnostic Plots**, load the **Analysis** tab, select the **Diagnostic Graphs** tab, and the following window will appear:



The main plot window will contain two data series:

1. the time-drawdown data
2. the drawdown derivative data (time vs. change in drawdown).

The drawdown derivative data series will be represented by a standard symbol with the addition of an X through the middle of the symbol.

On the right side of the window, you will see five time-drawdown graph templates, each one representing different aquifer conditions, and/or scenarios encountered during a pumping test. These include:

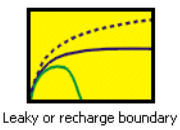
- Confined
- Leaky or Recharge Boundary
- Barrier Boundary
- Double Porosity (Fractured Flow) and Unconfined
- Well Effects

In the Diagnostic plots, the time (t) is plotted on the X axis, and the drawdown (s) is plotted on the y axis. There are two different representations are available:

1. Log-Log scale
2. Semi-log, whereby the drawdown (s) is plotted on a linear axis.

The scale type may be selected directly above the time-drawdown graph templates. Changing the plot type will display a new set of the graph templates, and also plot the observed drawdown data in the new scale.

Each diagnostic graph contains three lines:



- Theis type curve (dashed black line)
- Theoretical drawdown curve under the expected conditions (solid black line)
- Drawdown derivative curve (solid green line).

NOTE: The curves on the diagnostic plots assume a constant pumping rate from one pumping well; using a diagnostic plot with a variable rate pumping test will not provide meaningful results.

In some diagnostic plots, there is no distinguishable difference between the time vs. drawdown curves, and it may be difficult to diagnose the aquifer type and conditions. In this case, study the time vs. drawdown derivative curves, as they typically provide a clearer picture of the aquifer characteristics.

The diagnostic plots are available as a visual aid only; your judgement should coincide with further hydrogeological and geological assessment.

The theoretical drawdown graph templates are further explained below.

Confined Aquifer

In an ideal confined aquifer (homogeneous and isotropic, fully penetrating, small diameter well), the drawdown follows the Theis curve. When viewing the semi-log plot, the time-drawdown relationship at early pumping times is not linear, but at later pumping times it is. If a linear relationship like this is found, it should be used to calculate the hydraulic characteristics because the results will be much more accurate than those obtained by matching field data points with the log-log plot (Kruseman and de Ridder, 1990).

Unconfined Aquifer

The curves for the unconfined aquifer demonstrate a delayed yield. At early pumping times, the log-log plot follows the typical Theis curve. In the middle of the pumping duration, the curve flattens, which represents the recharge from the overlying, less permeable aquifer, which stabilizes the drawdown. At later times, the curve again follows a portion of the theoretical Theis curve.

The semi-log plot is even more characteristic; it shows two parallel straight-line segments at early and late pumping times. (Kruseman and de Ridder, 1990).

Double Porosity

The theoretical curve for double porosity is quite similar to that seen in an unconfined aquifer, which illustrates delayed yield. The aquifer is called double porosity, since there are two systems: the fractures of high permeability and low storage capacity, and the matrix blocks of low permeability and high storage capacity. The flow towards the well in this system is entirely through the fractures and is radial and in unsteady state. The flow from the matrix blocks into the fractures is assumed to be in pseudo-steady-state.

In this system, there are three characteristic components of the drawdown curve. Early in the pumping process, all the flow is derived from storage in the fractures. Midway through the pumping process, there is a transition period during which the matrix blocks feed their water at an increasing rate to the fractures, resulting in a (partly) stabilized drawdown. Later during pumping, the pumped water is derived from storage in both the fractures and the matrix blocks (Kruseman and de Ridder, 1990).

Leaky

In a leaky aquifer, the curves at early pumping times follow the Theis curve. In the middle of the pumping duration, there is more and more water from the aquitard reaching the aquifer. At later pumping times, all the water pumped is from leakage through the aquitard(s), and the flow to the well has reached steady-state. This means that the drawdown in the aquifer stabilizes (Kruseman and de Ridder, 1990).

Recharge Boundary

When the cone of depression reaches a recharge boundary, the drawdown in the well stabilizes. The field data curve then begins to deviate more and more from the theoretical Theis curve (Kruseman and de Ridder, 1990).

Barrier (Impermeable) Boundary

With a barrier boundary, the effect is opposite to that of a recharge boundary. When the cone of depression reaches a barrier boundary, the drawdown will double. The field data curve will then steepen, deviating upward from the theoretical Theis curve. (Kruseman and de Ridder, 1990). Analytically this is modelled by an additional pumping well (an image well). After this phase (in which the two drawdowns accumulate) and the curve again adapts itself to the Theis function.

Well Effects

Well effects, in particular storage in the pumping well, can contribute to delayed drawdown at the beginning of the pumping test. At early pumping, the drawdown data will deviate from the theoretical Theis curve, since there will be a storage component in the well. After this, in mid - late pumping times, the drawdown curve should represent the theoretical Theis curve. These well effects are more easily identified in the semi-log plot.

4.2.2 Analysis Plots and Options

The Analysis plots are the most important feature in **AquiferTest**. In the analysis graph, the data is fit to the type curve, and the corresponding aquifer parameters are determined. In the graph the data can be plotted linearly or logarithmically. The program calculates the Type curve automatically, and plots it on the graph. Above the graph, the analysis method is listed. To the right of the graph, in the **Analysis Navigator** panel, the aquifer parameters for each well are displayed in the **Results** frame, and can be manually modified using parameter controls. (for more information see “Manual Curve Fitting” on page 129).

Model Assumptions

The model assumptions control which solution method will be chosen for your data, and what superposition factors will be applied.

Using the diagnostic plots as a guide, select the appropriate **model assumptions**, and AquiferTest will select the appropriate **Analysis Method** from the **Analysis Navigator** panel. From here, you may continue to adjust the model assumptions in order to reach a more representative solution. Alternately, you may directly select the Analysis Method and AquiferTest will then select the corresponding model assumptions.

The following model assumptions are available for the pumping test solutions:

- Type: Confined, Unconfined, Leaky, Fractured
- Extent: Infinite, Recharge Boundary, Barrier Boundary
- Isotropy: Isotropic, Anisotropic
- Discharge: Constant, Variable
- Well Penetration: Fully, Partially

Each time a model assumption is modified, **AquiferTest** will attempt to recalculate the theoretical drawdown curve, and a new automatic fit must be applied by the user. If the automatic fit fails, then a manual curve fit can be done using the parameter controls.

Also, adjusting model assumptions may result in the addition of a new aquifer parameter(s), or removal of existing ones (apart from the usual parameters Transmissivity (T) and Storativity (S)). For example, if you change the aquifer type from confined to leaky, an additional parameter for hydraulic resistance (c) will be added for each well in the **Results** frame of the **Analysis Navigator** panel, and its value will be calculated. Alternately, changing the aquifer type back to confined will hide this parameter, and the c value will no longer appear in the **Results** frame.

NOTE: Model assumptions are not available for slug test solutions, nor for the Theis Recovery or Cooper-Jacob methods.

Dimensionless Graphs

AquiferTest also provides a dimensionless representation of the analysis graph. In this graph, time (t_D) and drawdown (s_D) are plotted without dimensions.

NOTE: Similar to the diagnostic plots, the dimensionless graph is appropriate for constant pumping rates only, and a single pumping well.

The following definitions are specified:

$$t_D = \frac{Tt}{r^2 S}$$

$$s_D = \frac{2\pi T s}{Q}$$

where,

T: Transmissivity

t: Time since beginning of pumping

r: radial distance to the pumping well

S: Storage coefficient

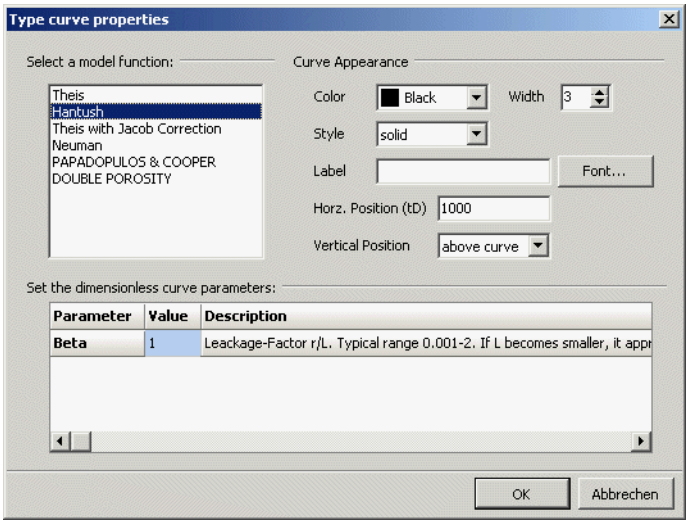
s: Drawdown

Q: pumping rate

Reference: Renard, P. (2001): Quantitative analysis of groundwater field experiments.- 222 S., ETH Zürich, unpublished. p. 41

Adding Type Curves

In the dimensionless mode, additional user-defined type curves may be added for an improved analysis. In the **Analysis Navigator** Panel, under **Type Curves**, click on the **Add Type** curve option, and the following dialogue will appear.



For each selected model function the dimensionless curve parameters must be defined.

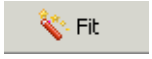
Define the range for the parameters. Also, define the color, line thickness, and description, so that it may be easily identified on the graph window.

Click **[OK]**, and the window will close and the type curve will be displayed on the graph. The curve name will appear as a new item under the **Type Curves** panel. Simply select this item to modify the curve later; or, right mouse click on the curve name in the panel and select **Delete** to remove it.

The type curve options for each solution method are explained in their respective sections below.

4.3 Analysis Parameters

4.3.1 Automatic Curve Fitting

To fit a type curve to your data using the Automatic Fit option, ensure that the desired well is highlighted at the top of the window in the **Analysis** tab, in the **Data from** box; if the well is selected, it will be outlined in a blue box. Then click the 

(Fit) icon from the analysis menu bar.

AquiferTest uses the “downhill simplex method” which is a minimizing algorithm for general non-linear functions, to automatically match the type curve to your data. If the automatic fit is successful, there will be a confirmation message. If the fit fails, there may be a warning message and a suggestion on what to do to fix it.

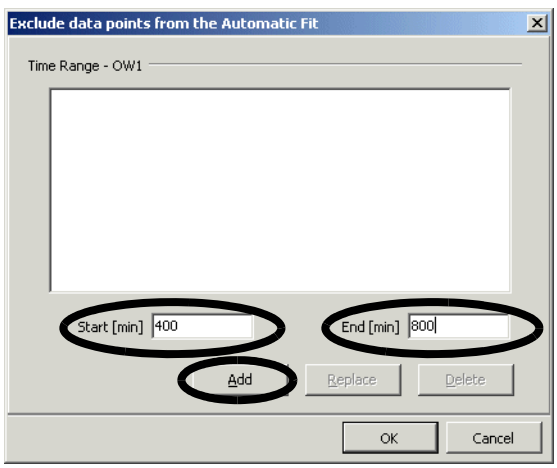
NOTE: If the automatic fit fails, or the fit results in the data being plotted off the graph window (i.e. the data is not visible), then a manual curve fitting should be used. This could also suggest aquifer conditions that are outside the typical range for Transmissivity and Storativity.

For more complex model assumptions, attempt a manual fit with appropriate parameter values for your site, (adjust the values for the parameters manually or enter numeric values in the parameter fields). THEN use the Automatic Fit feature.

Excluding Data Points from the Automatic Fit

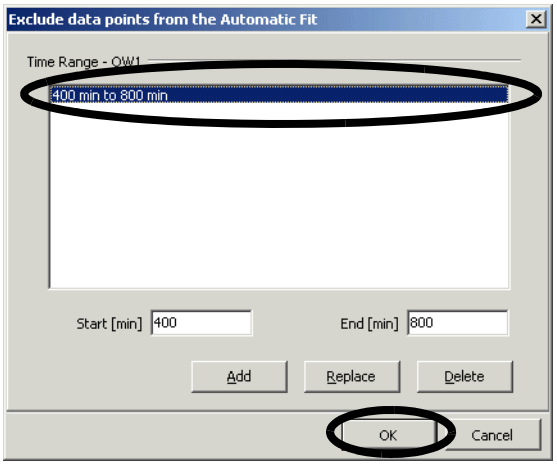
When data points are excluded from the analysis they remain visible on the graph, however they are no longer considered in the automatic fit calculations.

To exclude points from analysis click the (Exclude) button above the analysis graph and define the time range for the data points to be excluded:



Enter the time range, and press **[Add].**

Then, highlight the defined range and click **[OK]** to exclude the points.



Upon returning to the analysis graph, once again perform Automatic fit. **AquiferTest** will do an autofit on the remaining points, however the excluded points will still be visible.

For more information on excluding data points please see “Exclude” on page 71.

Define Analysis Time Range

Defining an analysis time range will restrict **AquiferTest** to performing calculations using only data points that fall within the defined boundaries. The points that fall outside these boundaries will neither be displayed on the graph nor be considered in the analysis.

To define the time range for an analysis select **Define analysis time range...** from the **Project Navigator** panel to the left of the analysis graph. In the window that appears, select the type of range you wish to impose on your data and enter the bounding values. Click **[OK]** to implement the changes and return to the analysis graph. Perform an Automatic fit on the modified dataset. Points not within the time range will be temporarily hidden from the graph.

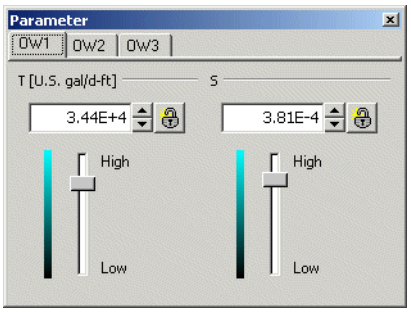
For more information on defining analysis time range, please see “Define analysis time range...” on page 51.

4.3.2 Manual Curve Fitting

The Automatic Fit may not always yield the most appropriate curve match, and as such, you can use a manual curve fit. Your professional judgement is essential for the proper assessment of the **AquiferTest** data. You are encouraged to use your knowledge of the local geologic and hydrogeologic settings of the test to manually fit the data to a type curve.

For the manual adjustment of the parameters, there are several options:

- Enter new parameter values manually in the fields in the **Results** panel.
- Use the **Parameter Controls**. The **Parameter Controls** window can be loaded by clicking on the (Parameter Controls) button, or by selecting **View/ Analysis Parameters**.



Use the options here to modify the parameter values, and achieve the optimal curve fit. In the parameter controls, there are several options:

- Enter new parameter values manually in their respective fields;
- Adjust the parameter values up/down using the slider controls;
- If the cursor is in the input field, the parameter can be adjusted by the use of the keyboard arrow keys: “up” will increase the value, - “down” will decrease the value (division and/or multiplication by a default factor 1.5)
- Use the up/down buttons adjacent to each respective parameter field.

The parameters can become fixed by clicking the “lock” button; by locking a parameter, the value will remain constant the next time an automatic fit is applied.

When the parameter is locked, the icon will appear as follows:

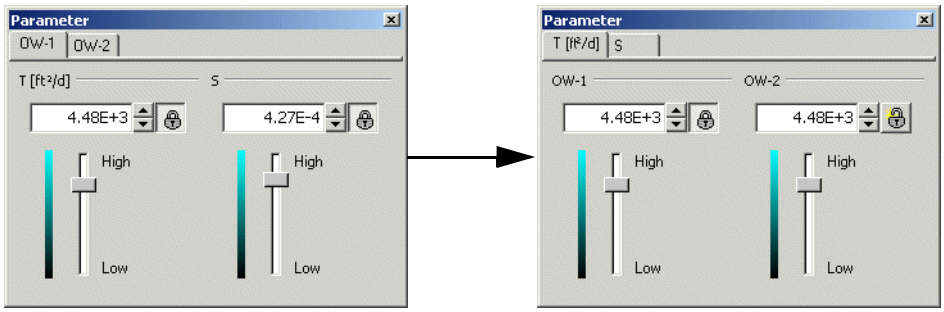
Using this feature, you can lock in a certain curve shape and then use the Autofit option and see the resulting drawdown. You can also lock parameters for use in:

- Predicting drawdown at other locations
- Fixing known parameter ratios (e.g. P value for Boundary barrier)
- Fixing known parameter values (e.g. Lambda for Double Porosity solution)

When a parameter is not locked, the icon will appear as follows: , and it will be considered when the Automatic fit is applied.

In the **Parameter Control** window, the parameters can be displayed by wells or by parameter type. Right mouse click anywhere in the Parameters window to change the display type.

By Well **By Parameter**



4.4 Theory of Superposition

The pumping test solution methods included with **AquiferTest** are:

- Theis
- Theis with Jacob Correction
- Hantush-Jacob
- Neuman
- Papadopulos - Cooper
- Warren Root - Double Porosity
- Boulton
- Hantush (Leaky, with storage in aquitard)
- Moench (Fractured flow, with skin)
- Agarwal Recovery
- Theis Recovery
- Cooper Jacob I: Time Drawdown
- Cooper Jacob II: Distance Drawdown
- Cooper Jacob III: Time Distance Drawdown

These methods each have some general assumptions:

- aquifer extends radially and infinitely
- single pumping well
- constant pumping rate
- fully penetrating well (except for the Neuman method)

These assumptions may be modified if the pumping test data are analyzed utilizing the theory of superposition. **AquiferTest** uses the theory of superposition to calculate drawdown in variable aquifer conditions. Superposition can be applied to any solution method.

Superposition may be used to account for the effects of pumping well interference, aquifer discontinuities, groundwater recharge, well/borehole storage and variable pumping rates. The differential equations that describe groundwater flow are linear in the dependent variable (drawdown). Therefore, a linear combination of individual solutions is also a valid solution. This means that:

- The effects of multiple pumping wells on the predicted drawdown at a point can be computed by summing the predicted drawdowns at the point for each well; and
- Drawdown in complex aquifer systems can be predicted by superimposing predicted drawdowns for simpler aquifer systems (Dawson and Istok, 1991).

In **AquiferTest**, the standard solution methods can be enhanced by applying superposition; the various superposition principles are explained below.

4.4.1 Variable Discharge Rates

Pumping rates from an aquifer are sometimes increased in several steps in order to better assess aquifer properties. In **AquiferTest**, drawdown calculated during variable discharge periods is analyzed using the superposition principle. Using the superposition principle,

two or more drawdown solutions, each for a given set of conditions for the aquifer and the well, can be summed algebraically to obtain a solution for the combined conditions.

For variable discharge rates, the following equation is used:

$$s(t) = \frac{Q_1}{4\pi T} W\left(\frac{r^2 S}{4Tt}\right) + \sum_{i=2}^{n} \frac{Q_i - Q_{i-1}}{4\pi T} W\left(\frac{r^2 S}{4T(t - t_{i-1})}\right)$$

(the equation shown here applies for the Theis solution).

where $t > t_{i-1}$

with

Q_1 = pumping rate starting from t=0
Q_i = pumping rate at pumping stage i
n = number of pumping stages

The drawdown at the time t corresponds to the drawdown caused by the initial pumping rate plus the sum of all drawdowns caused by the change of pumping rate.

For more information, please refer to “Analysis and Evaluation of Pumping Test Data” (Kruseman and de Ridder, 1990, p. 181).

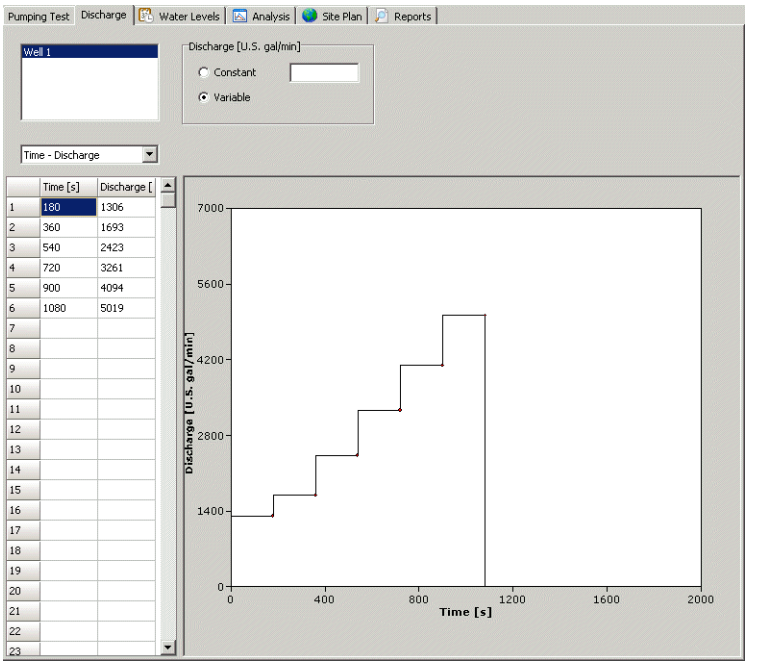
Entering Variable Discharge Rates

Ensure you have the time-discharge data formatted correctly when using a variable pumping rate analysis. The sample table below illustrates the pumping time and discharge rates for a pumping test:

Time (min.)	Discharge (m^3/d)
180	**1306**
360	**1693**
540	**2423**
720	**3261**
900	**4094**
1080	**5019**

When you enter time-discharge data in **AquiferTest**, your first entry is the initial pumping rate. Using the table above as an example, the pumping rate from 0-180 minutes was 1306 m^3/day. The second pumping rate from 180-360 minutes was 1693 m^3/day, and so on.

For your convenience, the figure below has been included to demonstrate the correct data format, in the **Discharge** tab:



Be sure to select "**Variable**" discharge type from the **Model assumptions** frame in the **Analysis Navigator** panel; otherwise, **AquiferTest** will average the pumping rates into one constant value.

4.4.2 Multiple Pumping Wells

Determining the cone of influence caused by one or more pumping wells can be a challenge. To do so one must assume that the aquifer is limitless; therefore, the cone of influence is also regarded as limitless. The cone of influence is considered mathematically finite only with a positive aquifer boundary condition.

In **AquiferTest**, multiple pumping wells can be considered using superposition. The principle states that the drawdown caused by one or more wells, is the sum of multiple wells superimposed into one. The following equation is used to superimpose a pumping rate for multiple pumping wells:

$$s = \sum_{i=1}^{n} \frac{Q_i}{4\pi T} W\left(\frac{r_i^2 S}{4Tt}\right)$$

with,

n = number of pumping/injection wells

Q_i = pumping rate at the well i

r_i = distance from the observation well to well i

It is important to notice that superimposition of groundwater flow causes the cone of depression to develop an eccentric form as it ranges further up gradient and lesser down gradient. In **AquiferTest**, this situation is not considered as the depression cone is symmetrical to all sides and extends over the stagnation point. This means representation of the cone of depression and calculation of the cone of influence does not consider overall groundwater flow.

4.4.3 Boundary Effects

Pumping tests are sometimes performed near the boundary of an aquifer. A boundary condition could be a recharge boundary (e.g. a river or a canal) or a barrier boundary (e.g. impermeable rock). When an aquifer boundary is located within the area influenced by a pumping test, the assumption that the aquifer is of infinite extent is no longer valid.

The delineation of the aquifer by an impermeable layer and/or a recharge boundary can also be considered using the superposition principle. According to this principle, the drawdown caused by two or more wells is the sum of the drawdown caused by each separate well. By taking imaginary (image) wells (pumping or injection) into account, you can calculate the parameters of an aquifer with a seemingly infinite extent. **AquiferTest** creates an imaginary pumping and/or injection well, which is added to the calculation.

To account for the boundary condition, a term is added to the Theis function:

$$s(r,t) = \frac{Q}{4\pi T}\left(\int_{u_r}^{\infty}\frac{e^{-u}}{u}du \pm \int_{u_i}^{\infty}\frac{e^{-u}}{u}du\right)$$

where,

$$u_r = \frac{r_r^2 S}{4\pi T}$$

and

$$u_i = \frac{r_i^2 S}{4\pi T}$$

where,

r_r = distance between observation well and real well

r_i = distance between observation well and imaginary well

The extension for boundary conditions will be demonstrated only in a confined aquifer, but its use in a semi-confined and unconfined aquifer occurs similarly. According to Stallman (in Ferris et al., 1962) the total drawdown is determined as:

$$s = s_r \pm s_i$$

s: total drawdown

s_r: drawdown caused by the real pumping well

$+s_i$: drawdown caused by the imaginary pumping well

$-s_i$: drawdown caused by the imaginary injection well

Using the new variable r_i, the user must enter a value for the parameter, *P*, when a boundary condition is applied in the **Model assumptions** frame:

$$P = \frac{r_i}{r_r}$$

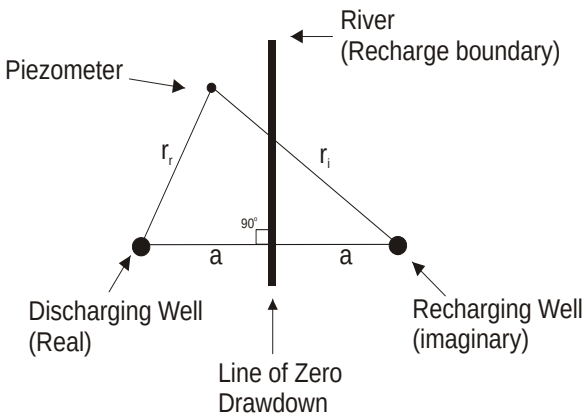
where P = ratio of r_i to r_r

The P value can be entered in the **Results** frame, in the **Analysis Navigator** panel. Once the value is entered, the parameter should be locked, since it is a constant value (i.e. the ratio between the distances is constant, and should not change during the automatic fit).

The explanation of each boundary type is further discussed below.

Recharge Boundary

For a recharge boundary (with an assumed constant head) two wells are used: a real discharge well and an imaginary recharge well. The imaginary well recharges the aquifer at a constant rate, Q, equal to the constant discharge rate of the real well. Both the real well and the imaginary well are equidistant from the boundary, and are located on a line normal to the boundary (Kruseman and de Ridder, 1990).



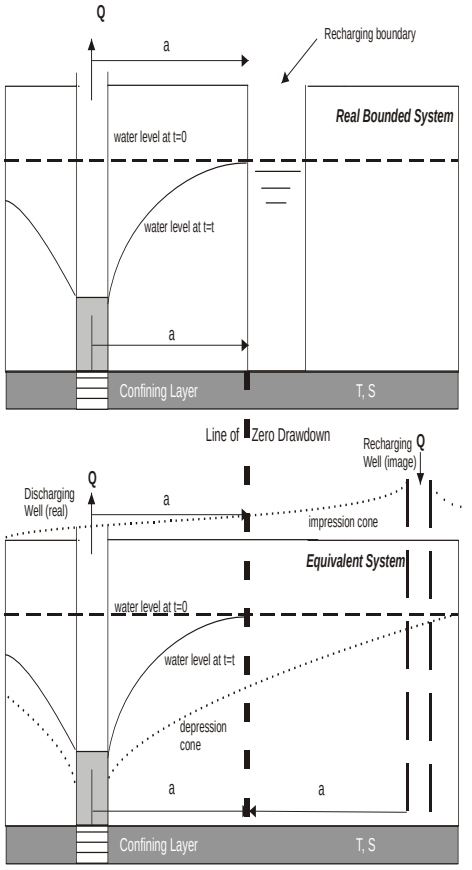
where,

a = distance between pumping well and the boundary

r_r = distance between observation well and real well

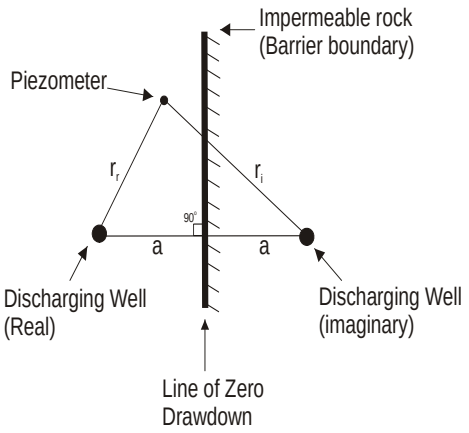
r_i = distance between observation well and imaginary well

There is a “line of zero drawdown” that occurs at the point of the recharge or barrier boundary. The cross-sectional view of the Stallman recharge condition is seen in the following figure:

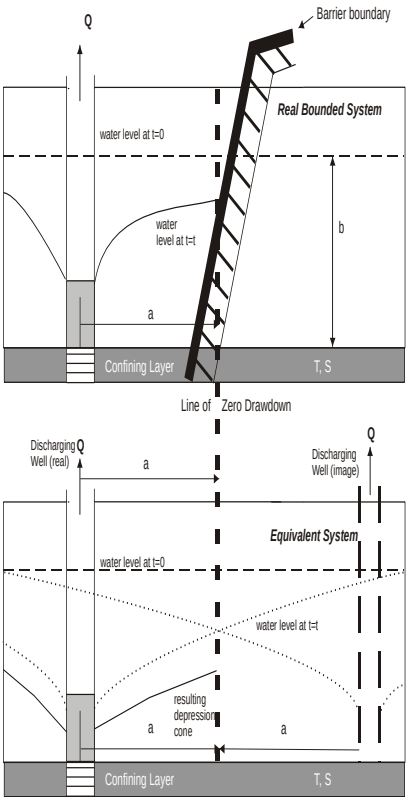


Barrier Boundary

For a barrier boundary, the imaginary system has two wells discharging at the same rate: the real well and the imaginary well. The image well induces a hydraulic gradient from the boundary towards the imaginary well that is equal to the hydraulic gradient from the boundary towards the real well.



The cross-sectional view of the Stallman Barrier condition is seen below:



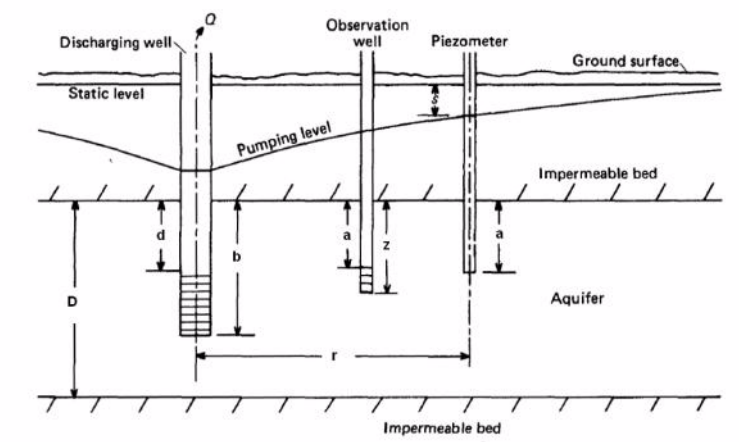
For more details, please see p. 109, Kruseman and de Ridder

4.4.4 Effects of Vertical Anisotropy and Partially Penetrating Wells

Pumping wells and monitoring wells often only tap into an aquifer, and may not necessarily fully penetrate the entire thickness. This means only a portion of the aquifer thickness is screened, and that both horizontal and vertical flow will occur near the pumping well. Since partial penetration induces vertical flow components in the vicinity of the well, the general assumption that the well receives water only from horizontal flow is no longer valid (Krusemann and de Ridder, 1990, p 159).

Consequently, as soon as there is a vertical flow component, the anisotropic properties of the aquifer should also be considered. If the aquifer is anisotropic, then the permeability in the horizontal direction is different from the vertical permeability.

To account for partially penetrating wells, the user must enter the values for the well screen lengths, the distance from the bottom of the screen to the top of the aquifer (b value) and the initial saturated aquifer thickness. (These parameters are defined in the **Pumping Test** tab). **AquiferTest** will then calculate the distance between the top of the well screen and the top of the aquifer, and the bottom of the well screen and the bottom of the aquifer, and uses these factors in the drawdown calculations. **AquiferTest** uses the well geometry after Reed (1980), shown in the following diagram.



AquiferTest uses the vertical flow correction developed by Weeks (1969):

$$s = \frac{Q}{4\pi T} W(u) + \delta s$$

(equation shown here is for confined aquifer).

with

W(u) = Theis well function

δ = difference in drawdown between the observed drawdowns and the drawdowns predicted by the Theis equation.

δ is computed as follows:

$$\delta s = \frac{Q}{4\pi T} f_s$$

For the calculation of f_s, two formulae exist:

- one for a piezometer, and
- one for observation wells

For a piezometer, f_s is modified, and calculated with:

$$f_{(s)} = \frac{2D}{\pi(b-d)} \sum_{n=1}^{\infty} \frac{1}{n} W(u, n\pi\beta') \left\{ \cos \frac{n\pi a}{D} \right\} \left\{ \sin \frac{n\pi b}{D} - \sin \frac{n\pi d}{D} \right\}$$

with

D: thickness

a: distance from aquifer top to bottom of piezometer

b: distance from top of aquifer to bottom of well screen, for the pumping well.

d: distance from top of aquifer to top of well screen, for the pumping well.

The calculation for β is as follows:

$$\beta' = \frac{r}{D} \sqrt{K_v / K_h}$$

with

r: distance from Pumping well to piezometer

K_v: vertical conductivity

K_h: horizontal conductivity

For the case where $t > SD/2K_v$, (S = storage coefficient) the function is:

$$W(u, n\pi\beta')$$

the modified Bessel' function of the 2nd order, is approximated:

$$2K_0(n\pi\beta')$$

AquiferTest uses the following formula for the computation of f_s at a piezometer:

$$f_{(s)} = \frac{4D}{\pi(b-d)} \sum_{n=1}^{\infty} \frac{1}{n} K_0(u, n\pi\beta') \left\{ \cos \frac{n\pi a}{D} \right\} \left\{ \sin \frac{n\pi b}{D} - \sin \frac{n\pi d}{D} \right\}$$

For observation wells, f_s is slightly different, and is defined as:

$$f_{(s)} = \frac{2D^2}{\pi^2 (b-d)(z-a)} \sum_{n=1}^{\infty} \frac{1}{n^2} W(u, n\pi\beta') \left\{ \sin \frac{n\pi z}{D} - \sin \frac{n\pi a}{D} \right\} \left\{ \sin \frac{n\pi b}{D} - \sin \frac{n\pi d}{D} \right\}$$

with

a: distance from top of aquifer to top of well screen in the observation well

z: distance from top of aquifer to bottom of well screen, in the observation well.

Using the same restriction as with the piezometer, t >SD/2Kv can be replaced with W(u, n, πβ') with 2 K_o (n, πβ') and the formula used by **AquiferTest** reads:

$$f_{(s)} = \frac{4D^2}{\pi^2 (b-d)(z-a)} \sum_{n=1}^{\infty} \frac{1}{n^2} K_0(u, n\pi\beta') \left\{ \sin \frac{n\pi z}{D} - \sin \frac{n\pi a}{D} \right\} \left\{ \sin \frac{n\pi b}{D} - \sin \frac{n\pi d}{D} \right\}$$

NOTE: The corrections for partial penetration effect and anisotropy require significant computing resources. As such, it is recommended to first complete a calculation with fully penetrating wells, and only after the model function is fitted, to apply the correction for partially penetrating wells.

4.5 Pumping Test Background

4.5.1 Radial Flow to a Well in a Confined Aquifer

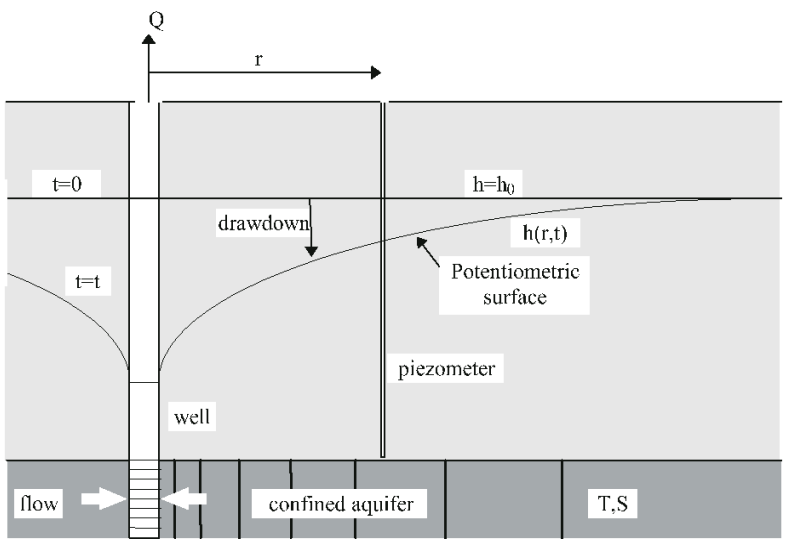
The partial differential equation that describes saturated flow in two horizontal dimensions in a confined aquifer is:

$$\frac{\partial^2 h}{\partial x^2} + \frac{\partial^2 h}{\partial y^2} = \frac{S}{T}\frac{\partial h}{\partial t}$$

Written in terms of radial coordinates, the equation becomes:

$$\frac{\partial^2 h}{\partial r^2} + \frac{1}{r}\frac{\partial h}{\partial r} = \frac{S}{T}\frac{\partial h}{\partial t}$$

The mathematical region of flow, illustrated below, is a horizontal one-dimensional line through the aquifer from $r = 0$ at the well to $r = \infty$ at the infinite extremity.



The initial condition is:

$$h(r,0) = h_0 \quad for\ all\ r$$

where h_0 is the initial hydraulic head (i.e., the piezometric surface is initially horizontal).

The boundary conditions assume that no drawdown occurs at an infinite radial distance:

$$h(\infty,t) = h_0 \quad for\ all\ t$$

and that a constant pumping rate, Q, is used:

$$\lim_{r \to 0} \left(r \frac{\partial h}{\partial r}\right) = \frac{Q}{2\pi T} \quad for\ t > 0$$

The solution of the above equation describes the hydraulic head at any radial distance, r, at any time after the start of pumping.

4.6 Pumping Test Methods - Fixed Assumptions

The following pumping test methods require a fixed set of assumptions; as such, these assumptions may not be modified on the Analysis plot. These include:

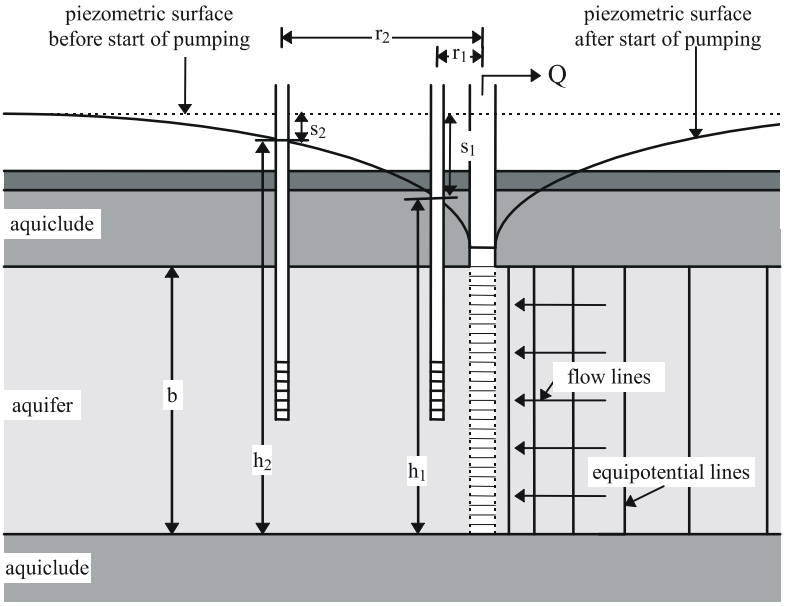
- Theis Recovery Analysis
- Cooper Jacob Methods
  - Cooper Jacob I: Time-Drawdown
  - Cooper Jacob II: Distance-Drawdown
  - Cooper Jacob III: Time-Distance Drawdown

4.6.1 Theis Recovery Test (confined)

When the pump is shut down after a pumping test, the water level inside the pumping and observation wells will start to rise. This rise in water level is known as residual drawdown (s'). Recovery-test measurements allow the transmissivity of the aquifer to be calculated, thereby providing an independent check on the results of the pumping test.

Residual drawdown data can be more reliable than drawdown data because the recovery occurs at a constant rate, whereas constant discharge pumping is often difficult to achieve in the field. Residual drawdown data can be collected from both the pumping and observation wells.

Strictly applied, this solution is appropriate for the conditions shown in the following figure. However, if additional limiting conditions are satisfied, the Theis recovery solution method can also be used for leaky, unconfined aquifers and aquifers with partially penetrating wells (Kruseman and de Ridder, 1990, p. 183).



According to Theis (1935), the residual drawdown, after pumping has ceased, is

$$s' = \frac{Q}{4\pi T} W(u) - W(u')$$

where:

$$u = \frac{r^2 S}{4Tt} \qquad u' = \frac{r^2 S'}{4Tt'}$$

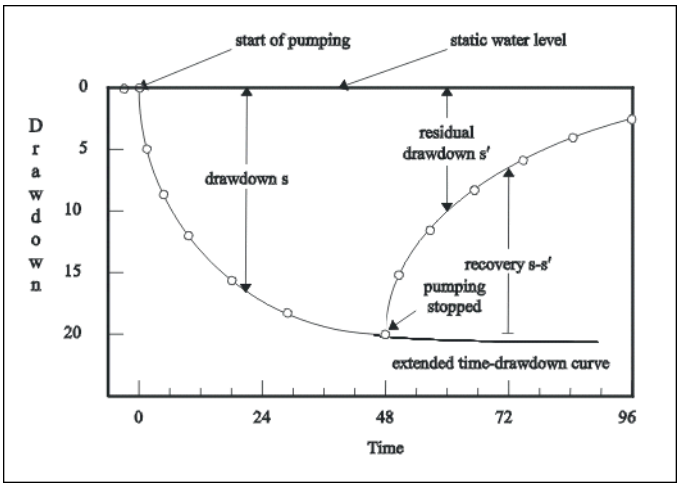
s' = residual drawdown

r = distance from well to piezometer

T = transmissivity of the aquifer (KD)

S and *S'* = storativity values during pumping and recovery respectively.

t and *t'* = elapsed times from the start and ending of pumping respectively.



Using the approximation for the well function, W(u), shown in the Cooper-Jacob method, this equation becomes:

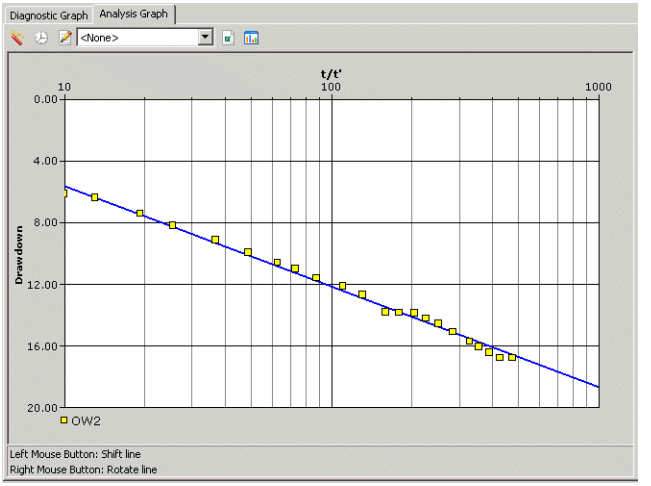
$$s' = \frac{Q}{4\pi T}\left(\ln\frac{4Tt}{r^2 S} - \ln\frac{4Tt'}{r^2 S'}\right)$$

When S and S' are constant and equal and T is constant, this equation can be reduced to:

$$s' = \frac{2.3Q}{4\pi T}\log\left(\frac{t}{t'}\right)$$

To analyze the data, s' is plotted on the logarithmic Y axis and time is plotted on the linear X axis as the ratio of t/t' (total time since pumping began divided by the time since the pumping ceased).

An example of a Theis Recovery analysis graph has been included below:



An example of a Theis Recovery analysis is available in the project: AquiferTest\Examples\Theis_Recovery.HYT

The Theis Recovery Solution assumes the following:

- The aquifer is confined and has an “apparent” infinite extent
- The aquifer is homogeneous, isotropic, and of uniform thickness over the area influenced by pumping
- The piezometric surface was horizontal prior to pumping
- The well is fully penetrating and pumped at a constant rate
- Water removed from storage is discharged instantaneously with decline in head
- The well diameter is small, so well storage is negligible

The data requirements for the Theis Recovery Solution are:

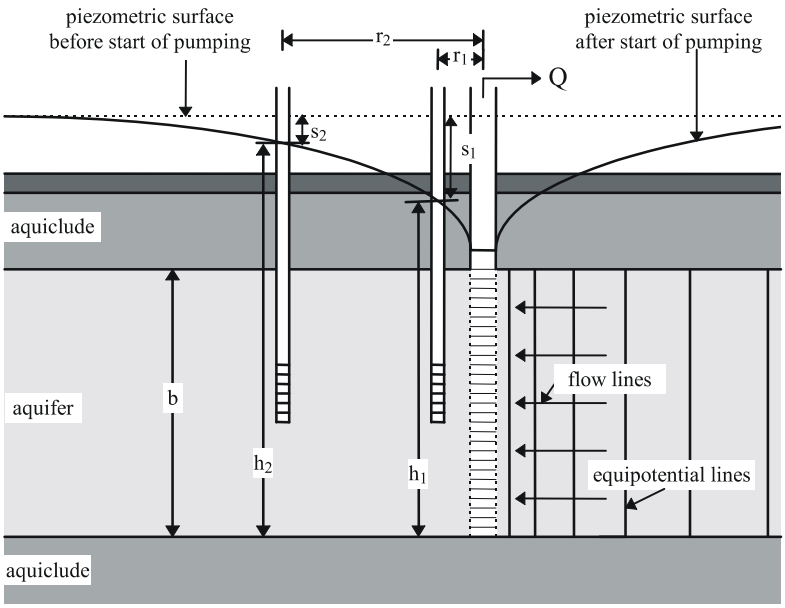
- Recovery vs. time data at a pumping or observation well
- Distance from the pumping well to the observation well
- Pumping rate and duration

4.6.2 Cooper-Jacob Method (confined; small r or large time)

The Cooper-Jacob (1946) method is a simplification of the Theis method valid for greater time values and decreasing distance from the pumping well (smaller values of *u*). This method involves truncation of the infinite Taylor series that is used to estimate the well function W(u). Due to this truncation, not all early time measured data is considered to be valid for this analysis method. The resulting equation is:

$$s = \left(\frac{2.3Q}{4\pi T}\right) \log_{10}\left(\frac{2.25Tt}{Sr^2}\right)$$

This solution is appropriate for the conditions shown in the following figure.



The Cooper-Jacob Solution assumes the following:

- The aquifer is confined and has an “apparent” infinite extent
- The aquifer is homogeneous, isotropic, and of uniform thickness over the area influenced by pumping
- The piezometric surface was horizontal prior to pumping
- The well is pumped at a constant rate
- The well is fully penetrating
- Water removed from storage is discharged instantaneously with decline in head
- The well diameter is small, so well storage is negligible
- The values of *u* are small (rule of thumb $u < 0.01$)

In AquiferTest, it is possible to define different values of u for the validity line. For more details, see “Constants tab” on page 113.

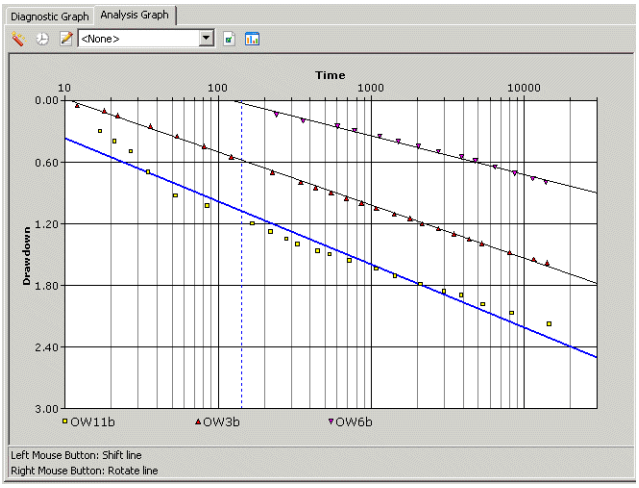
Cooper-Jacob I: Time-Drawdown Method

The above equation plots as a straight line on semi-logarithmic paper if the limiting condition is met. Thus, straight-line plots of drawdown versus time can occur after sufficient time has elapsed. In pumping tests with multiple observation wells, the closer wells will meet the conditions before the more distant ones. Time is plotted along the logarithmic X axis and drawdown is plotted along the linear Y axis.

Transmissivity and storativity are calculated as follows:

$$T = \frac{2.3Q}{4\pi\Delta s} \qquad S = \frac{2.25Tt_0}{r^2}$$

An example of a Cooper-Jacob Time-Drawdown analysis graph has been included below:



An example of a CooperJacob I analysis is available in the project: AquiferTest\Examples\CooperJacob1.HYT

The data requirements for the Cooper-Jacob Time-Drawdown Solution method are:

- Drawdown vs. time data at an observation well
- Finite distance from the pumping well to the observation well
- Pumping rate (constant)

Cooper-Jacob II: Distance-Drawdown Method

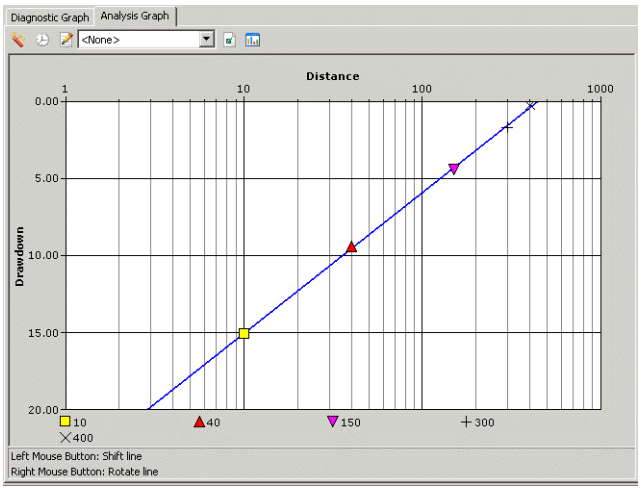
If *simultaneous* observations of drawdown in three or more observation wells are available, a modification of the Cooper-Jacob method may be used. The observation well distance is plotted along the logarithmic X axis, and drawdown is plotted along the linear Y axis.

Transmissivity and storativity are calculated as follows:

$$T = \frac{2.3Q}{2\pi\Delta s} \qquad S = \frac{2.25Tt_0}{r_0^{\,2}}$$

where r_0 is the distance defined by the intercept of the zero-drawdown and the straight-line though the data points.

An example of a Cooper-Jacob Distance-Drawdown analysis graph has been included below:



An example of a CooperJacob II analysis is available in the project: AquiferTest\Examples\CooperJacob2.HYT

The data requirements for the Cooper-Jacob Distance-Drawdown Solution method are:

- Drawdown vs. time data at three or more observation wells
- Distance from the pumping well to the observation wells
- Pumping rate (constant)

Both distance and drawdown values *at a specific time* are plotted, so you must specify this time value.

Cooper-Jacob III: Time-Distance-Drawdown Method

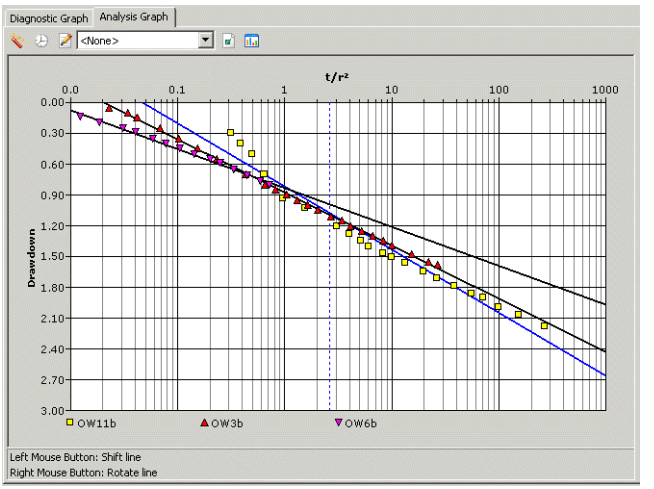
As with the Distance-Drawdown Method, if simultaneous observations are made of drawdown in three or more observation wells, a modification of the Cooper-Jacob method may be used. Drawdown is plotted along the linear Y axis and t/r^2 is plotted along the logarithmic X axis.

Transmissivity and storativity are calculated as follows:

$$T = \frac{2.3Q}{4\pi\Delta s} \qquad S = \frac{2.25Tt_0}{r_0^{\,2}}$$

where r_0 is the distance defined by the intercept of the zero-drawdown and the straight-line though the data points.

An example of a Cooper-Jacob Time-Distance-Drawdown analysis graph has been included in the following figure:



An example of a CooperJacob III analysis is available in the project: AquiferTest\Examples\CooperJacob3.HYT

The data requirements for the Cooper-Jacob Time-Distance-Drawdown Solution method are:

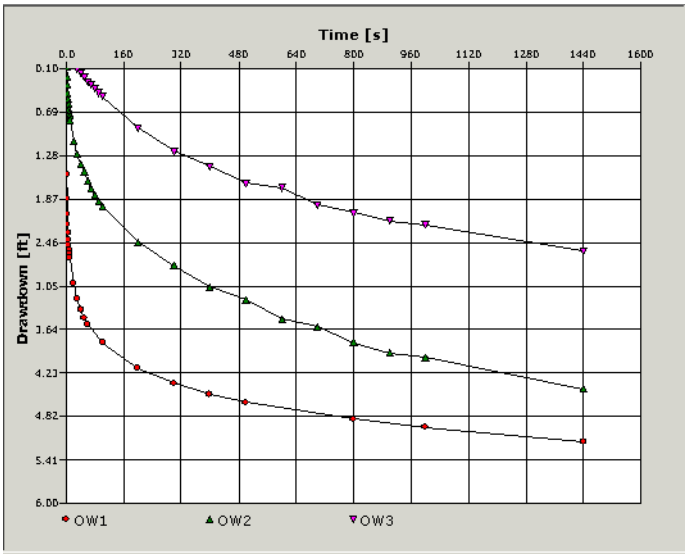
- Drawdown vs. time data at three or more observation wells
- Distance from the pumping well to the observation wells
- Pumping rate (constant)

4.7 Pumping Test Methods

Before doing the pumping test analysis, it is helpful to plot the time-drawdown data, or the time vs. drawdown with variable discharge rates. These plots are explained below.

4.7.1 Drawdown vs. Time

A preliminary graph that displays your drawdown versus time data. This is available in the **Analysis** tab.



When the drawdown vs. time plot is selected, the **Model assumptions** frame is not accessible in the **Analysis Navigator** panel.

To create an analysis, select one of the solution methods from the **Analysis Navigator** panel.

4.7.2 Drawdown vs. Time with Discharge

The discharge data can also be displayed on the Drawdown vs. Time plot. This graph can be useful for visualizing changes in drawdown that occur as a result of variable discharge rates.

To view the discharge plot, select a Drawdown vs. Time plot. In the **Display** frame (in the **Analysis Navigator** panel), enable the **Discharge Rate** option.

The discharge info will then appear at the bottom half of the time drawdown plot. In addition, a new node Discharge Axis will appear in the Analysis panel.

⊞ Time axis	
⊞ Drawdown axis	
⊟ Discharge axis	
Title	Discharge
Minimum	Auto
Maximum	Auto
Show Values	☑
Value format	0.#####
Major unit	5
Gridlines	☑
Percentage of height	30
Fill area	☑
Fill color	Yellow

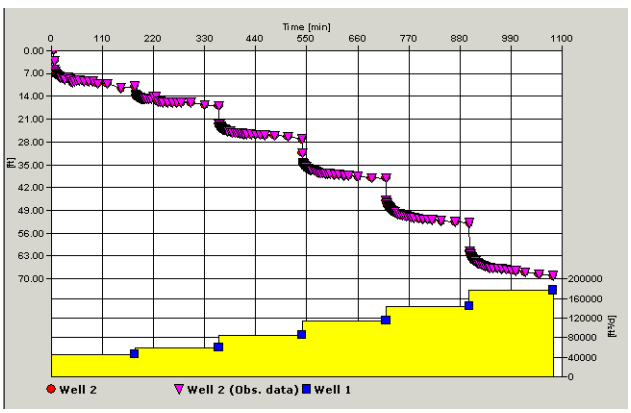
In here, you can specify several options:

- **Percentage of Height**: specify the proportions of the graphs; for example, if 50 percent is specified, then the discharge data will consume the lower 50 percent of the time drawdown plot.
- **Fill area:** fill in the area under the discharge line
- **Fill color**: specify a color for the filled area.

NOTE: The fill options should be used with one pumping well only, since it may result in overlapping the lines/fills if used with more than one well.

The Discharge axis will use the same label fonts as defined for the drawdown axis.

An example of a time-drawdown plot with discharge is shown below:



4.7.3 Confined - Theis

Theis (1935) developed an analytical solution for the equations presented in the previous section as follows:

$$s(r,t) = \frac{Q}{4\pi T}\int_{u}^{\infty}\frac{e^{-u}\,du}{u} \qquad u = \frac{r^2 S}{4Tt}$$

For the specific definition of *u* given above, the integral is known as the *well function*, *W(u)* and can be represented by an infinite Taylor series of the following form:

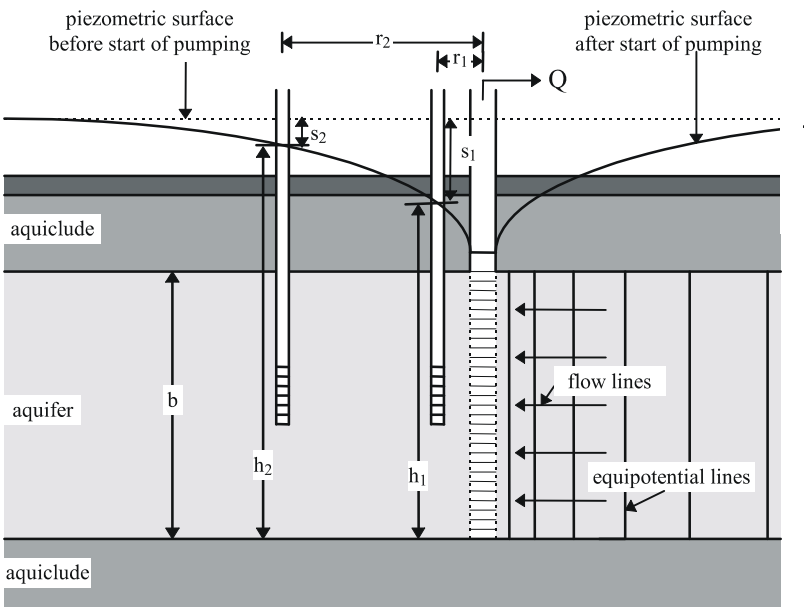
$$W(u) = -0.5772 - \ln(u) + u - \frac{u^2}{2 \cdot 2!} + \frac{u^3}{3 \cdot 3!} - \cdots$$

Using this function, the equation becomes:

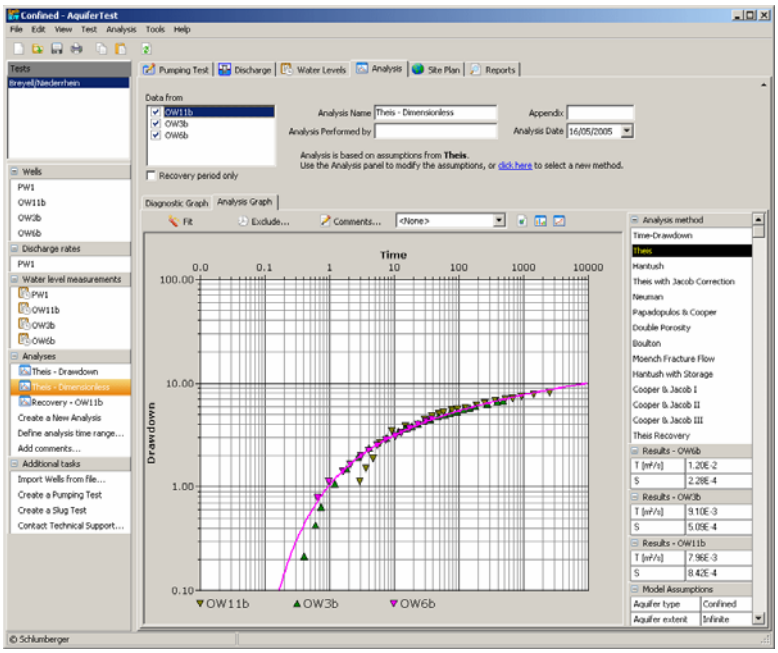
$$s = \frac{Q}{4\pi T} W(u)$$

The line on a log-log plot with *W(u)* along the Y axis and 1/*u* along the X axis is commonly called the *Theis curve*. The field measurements are plotted as *t* or t/r^2 along the X axis and *s* along the Y axis. The data analysis is done by matching the line drawn through the plotted observed data to the Theis curve.

The solution is appropriate for the conditions shown in the following figure:



An example of the Theis graph is shown below:



In this example, the dimensionless view is shown. An example of a Theis analysis is available in the project: AquiferTest\Examples\Confined.HYT.

The Data requirements for the Theis solution are:

- Drawdown vs. time at an observation well, or from the pumping well
- Finite distance from the pumping well to observation well
- Pumping rate

The Theis solution can be used as either a single-well solution, or in combination with drawdown data from an observation well. If used as a single-well solution, the pumping well is used as the discharge well and as the observation point at which drawdown measurements were taken. However, the user should be aware of well effects when analyzing a single well solution.

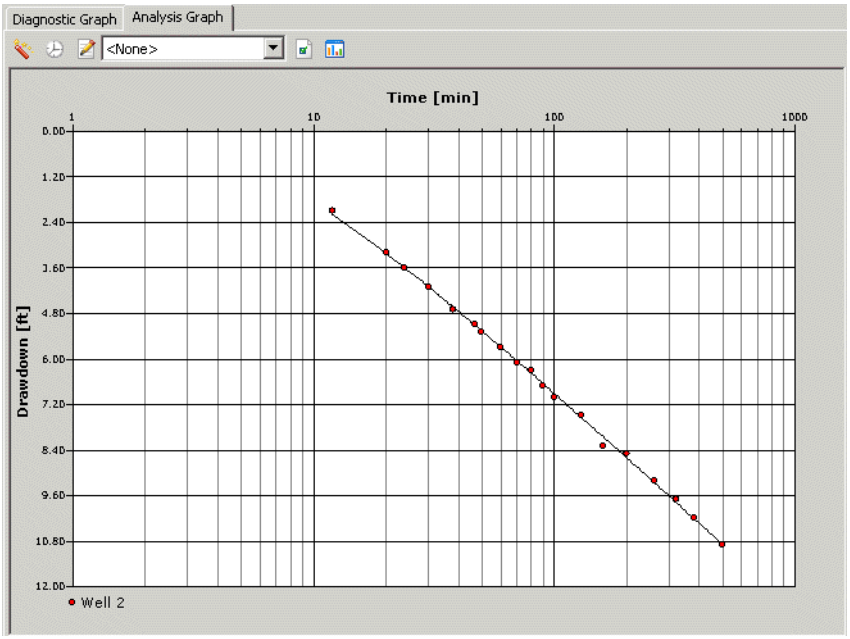
Dimensionless Parameters

Dimensionless parameters are required for the type curves in the Dimesionless view.

For the Theis method, no additional parameters are required.

Theis - Straight Line Analysis

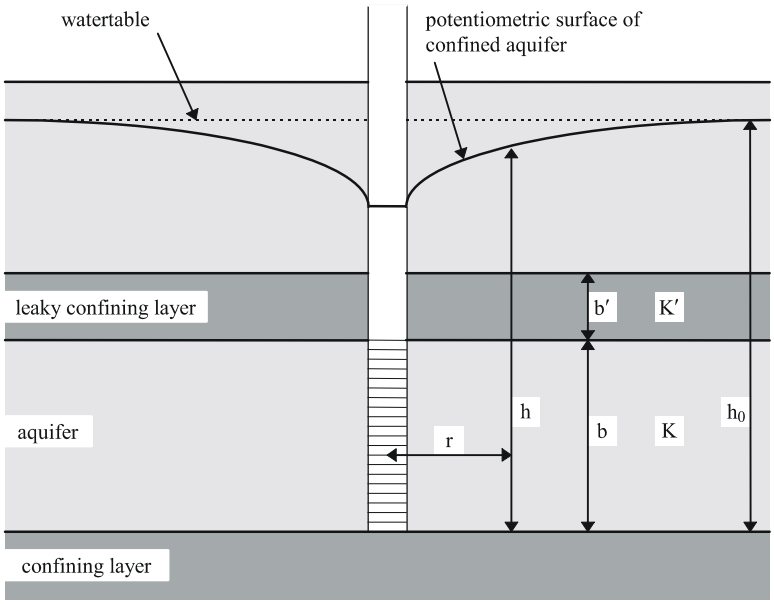
The Theis analysis can also be done using a semi-log straight line analysis; similar to the Cooper-Jacob analysis. An example is shown below.



In this example, the time data is plotted on a logarithmic axis, and the drawdown axis is linear.

4.7.4 Leaky - Hantush-Jacob (Walton)

Most confined aquifers are not totally isolated from sources of vertical recharge. Less permeable layers, either above or below the aquifer, can leak water into the aquifer under pumping conditions. Walton developed a method of solution for pumping tests (based on Hantush-Jacob, 1955) in leaky-confined aquifers with unsteady-state flow. The conditions for the leaky aquifer are shown below.



In the case of leaky aquifers, the well function W(u) can be replaced by the function Walton W(u, r/L) or Hantush W(u, B), and the solution becomes:

$$s = \frac{Q}{4\pi T} W\left(u, r/L\right)$$

where

$$L = \sqrt{Tc}$$

L = leakage factor (the leakage factor is termed β when used with the Hantush method)

and T = KD

where,

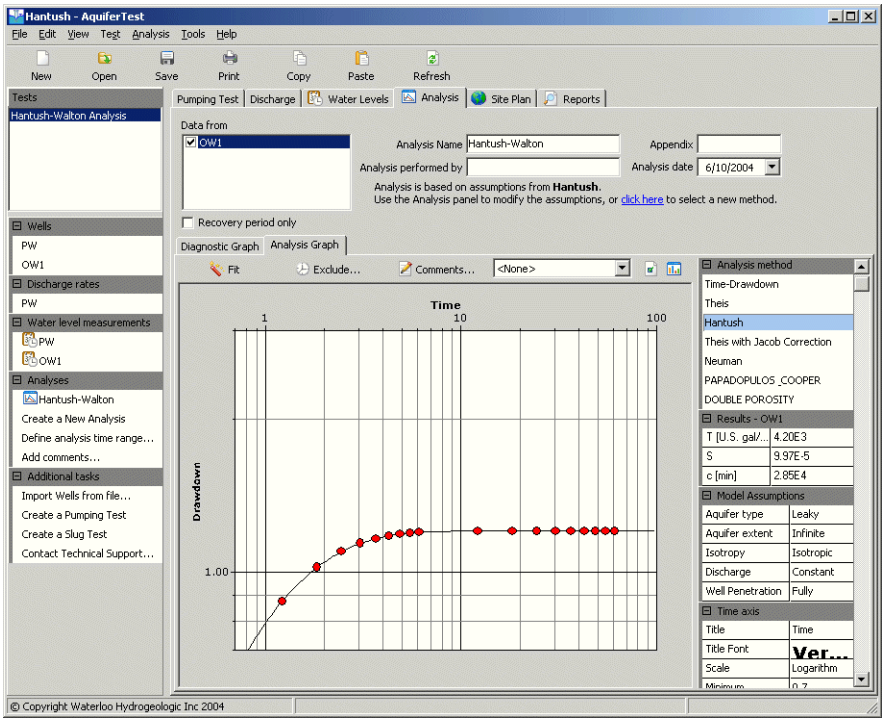
T = Transmissivity

K = Conductivity

D = saturated aquifer thickness

In **AquiferTest**, the model parameter C (hydraulic resistance, units [time]) is used with the Hantush method. The larger C, the smaller and/or more slowly the infiltration is due to Leakage. The C value must be defined for each data set, in the **Results** frame of the **Analysis Navigator** panel.

An example of a Hantush-Jacob analysis graph has been included below:



In this example, the dimensionless view is shown. An example of a Hantush-Jacob analysis is available in the project: AquiferTest\Examples\Leaky.HYT.

The data requirements for the Hantush-Jacob (no aquitard storage) Solution are:

- Drawdown vs. time data at an observation well
- Distance from the pumping well to the observation well
- Pumping rate
- β value: leakage factor

Dimensionless Parameters

For Hantush the dimensionless curve parameter β is defined, which characterizes the leakage.

The leakage factor, β, and the hydraulic resistance, c, are defined as:

$$\beta = \frac{r}{B}$$

with

$$B = \sqrt{Tc} = \sqrt{T\frac{D'}{K'}}$$

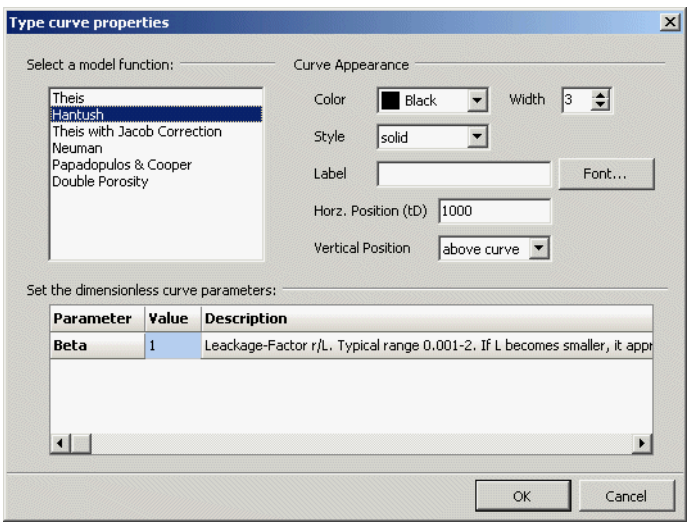
c: hydraulic resistance [time]

D': saturated thickness of the leaky Aquitard

K': vertical hydraulic conductivity of the leaky Aquitard

If K' = 0 (non-leaky aquitard) then r/B = 0 and the solution reduces to the Theis solution for a confined system.

A log/log scale plot of the relationship *W(u,r/B)* along the Y axis versus 1/*u* along the X axis is used as the type curve as with the Theis method. The field measurements are plotted as *t* along the X axis and *s* along the Y axis. The data analysis is done by curve matching.



The leakage factor β must be greater than 3 times the saturated aquifer thickness.

4.7.5 Hantush - Storage in Aquitard

Hantush (1960) presented a method of analysis that takes into account the storage changes in the aquitard. For small values of pumping time, he gives the following drawdown equation for unsteady flow (Kruseman and de Ridder, 1990):

$$s = \frac{Q}{4\pi KD} W(u, \beta)$$

where

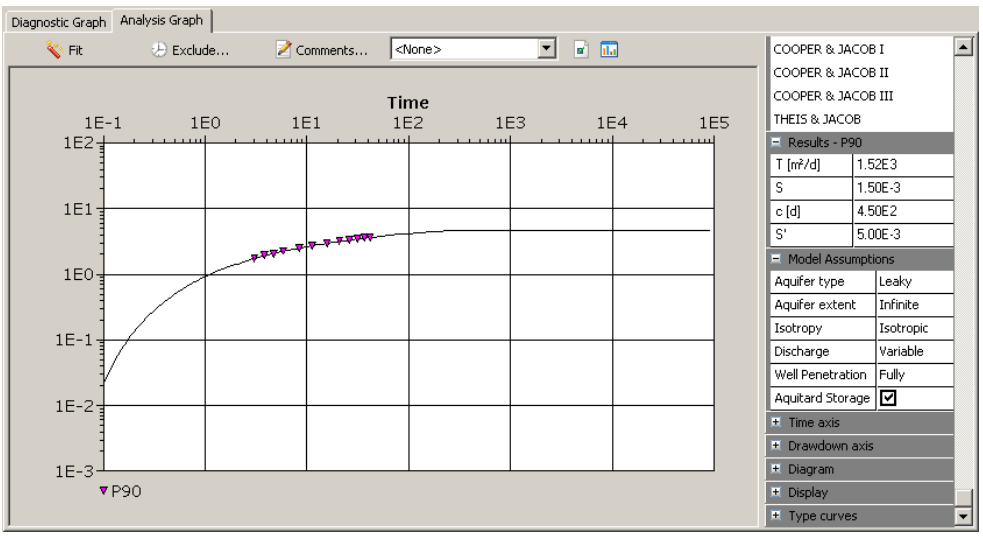
$$u = \frac{r^2 S}{4KDt}$$

$$\beta = \frac{r}{4}\sqrt{\frac{K'/D'}{KD} \times \frac{S'}{S}}$$

S' = aquitard storativity

$$W(u,\beta) = \int_u^{\infty} \frac{e^{-y}}{y} erfc \frac{\beta\sqrt{u}}{\sqrt{y(y-u)}} dy$$

An example of a dimensionless Hantush with Storage analysis graph has been included below:



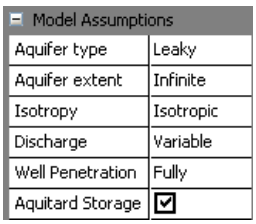
Hantush's curve-fitting method can be used if the following assumptions and conditions are satisfied:

- The flow to the well is in at unsteady state
- The water removed from storage in the aquifer and the water supplied by leakage from the aquitard is discharged instantaneously with decline of head
- The diameter of the well is very small,i.e. the storage in the well can be neglected.
- The aquifer is leaky

- The aquifer and the aquitard have a seemingly infinite areal extent
- The flow in the aquitard is vertical
- The drawdown in the unpumped aquifer (or in the aquitard, if there is no unpumped aquifer) is negligible.
- The aquitard is compressible, i.e. the changes in aquitard storage are appreciable
- t < S'D'/10K'

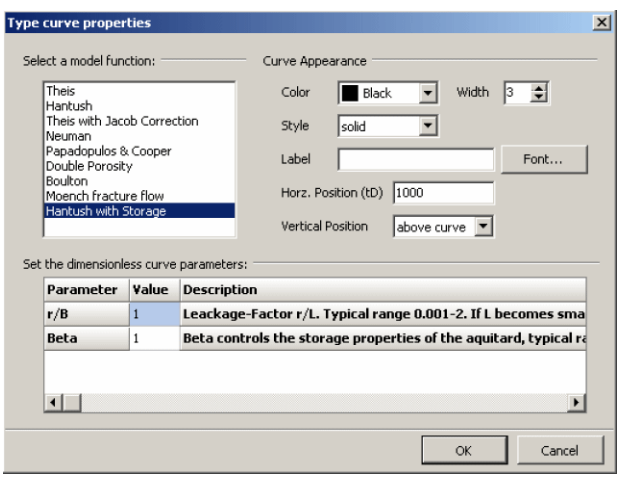
Only the early-time drawdown data should be used so as to satisfy the assumption that the drawdown in the aquitard (or overlying unpumped aquifer) is negligible.

To estimate the aquitard storativity value, S', ensure that the **Aquitard Storage** option is selected under the Model Assumptions frame, as shown below.



Dimensionless Parameters

Dimensionless parameters are required for the type curves in the dimensionless view.



The leakage factor, r/B, is defined as:

$$\frac{r}{B} = \frac{r}{L}$$

Where:

$$L = \sqrt{KDc}$$

KD: transmissivity

c: hydraulic resistance of the aquitard

Typical values for r/B range from 0.001 - 2.

Beta controls the storage properties of the aquitard and is defined below:

$$\beta = \frac{r}{4}\sqrt{\frac{K'/D'}{KD} \times \frac{S'}{S}}$$

Where:

S' = aquitard storativity

Typical values for Beta range from 0.05 - 1

An example of a Hantush - Storage in Aquitard analysis is available in the project: AquiferTest\Examples\Hantush Storage.HYT

The table below illustrates a comparison between the results in AquiferTest 4.2 and those published in Kruseman and de Ridder (1990) on page 93.

	AquiferTest 4.2	**Published** Kruseman and de Ridder, 1990 p.93
T	1.52E-3	1.15E-3
S	1.50E-3	1.50E-3
c[d]	4.50E2	4.50E2
S‘	5.00E-3	5.00E-3

4.7.6 Unconfined, Isotropic - Theis with Jacob Correction

The water table in an unconfined aquifer is equal to the elevation head (potential). Transmissivity is no longer constant, and it will decrease with increasing drawdown. This means that there is not only horizontal flow to the well, but there is also a vertical component, which will increase the closer you get to the well.

Since transmissivity in unconfined aquifers is not constant, there is no closed solution for this aquifer type. That is why the measured drawdown is corrected, and the pumping test is interpreted as being in a confined aquifer.

The Jacob modification (Jacob, 1944) applies to unconfined aquifers only when delayed yield is not an issue, and when drawdowns are small relative to the total saturated thickness (Neuman, 1975). Delayed yield is present in most unconfined aquifers at “early times” during the pump test, and is only absent at “late times” when the drawdown approximates the Theis curve. As such, Jacob’s correction should only be applied to late-time drawdown data (Kruseman and DeRidder, 1994).

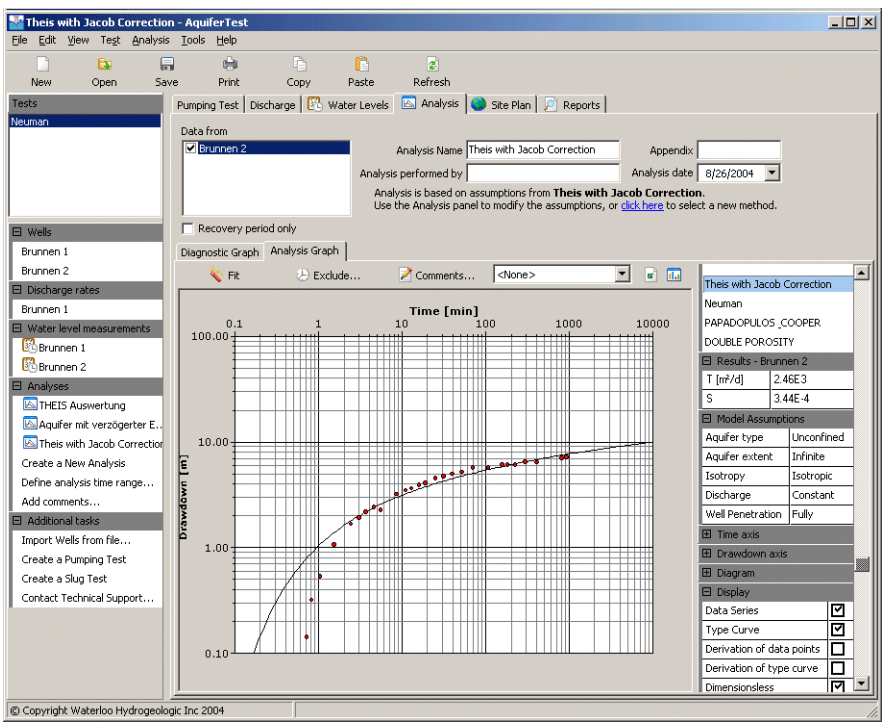
Jacob (1944) proposed the following correction

$$s_{cor} = s - (s^2/2D)$$

where:

s_{cor} = the corrected drawdown
s = measured drawdown
D = original saturated aquifer thickness

An example of a Theis (Jacob Correction) analysis graph has been included below:



In this example, the dimensionless view is shown. An example of a Theis (Jacob Correction) analysis is available in the project: AquiferTest\Examples\Unconfined.HYT.

Dimensionless Parameters

There are no additional type curve parameters for this solution method.

4.7.7 Unconfined, Anisotropic

For an unconfined, anisotropic aquifer, AquiferTest provides two options: Neuman or Boulton. The Neuman analysis can be demanding on your system resources, due to the complex calculations for the anisotropy. In some cases, the Boulton analysis may be a better choice. AquiferTest provides the option to define which analysis to use as default when specifying “Anisotropic and Unconfined” in the Model Assumptions. For more details, “General Tab” on page 112.

Neuman

Neuman (1975) developed a solution method for pumping tests performed in unconfined aquifers, which can be used for both fully or partially penetrating wells.

When analyzing pumping test data from unconfined aquifers, one often finds that the drawdown response fails to follow the classical Theis (1935) solution. When drawdown is plotted versus time on logarithmic paper, it tends to delineate an inflected curve consisting of:

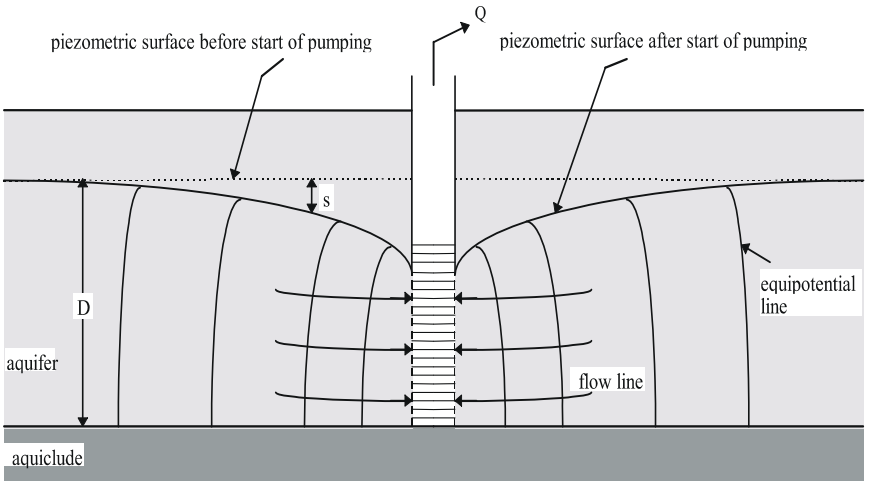
(1) a steep segment at early time;

(2) a flat segment at intermediate time; and

(3) a somewhat steeper segment at later time.

The early segment indicates that some water is released from aquifer storage instantaneously when drawdown increases. The intermediate segment suggests an additional source of water, which is released from storage with some delay in time. When most of the water has been derived from this additional source, the time-drawdown curve becomes relatively steep again. In the groundwater literature, this phenomenon has been traditionally referred to as “delayed yield” (Neuman, 1979).

This solution is appropriate for the conditions shown in the following figure.



The equation developed by Neuman representing drawdown in an unconfined aquifer is given by:

$$s = \frac{Q}{4\pi T} W(u_A, u_B, \beta)$$

where:

$W(u_A, u_B, \beta)$ is known as the *unconfined well function*

$u_A = r^2 S / 4Tt$ (Type A curve for early time)

$u_B = r^2 S_y / 4Tt$ (Type B curve for later time)

$\beta = r^2 K_v / D^2 K_h$

K_v, K_h: vertical and/or horizontal permeability

Sy: Specific Yield, usable pore volume

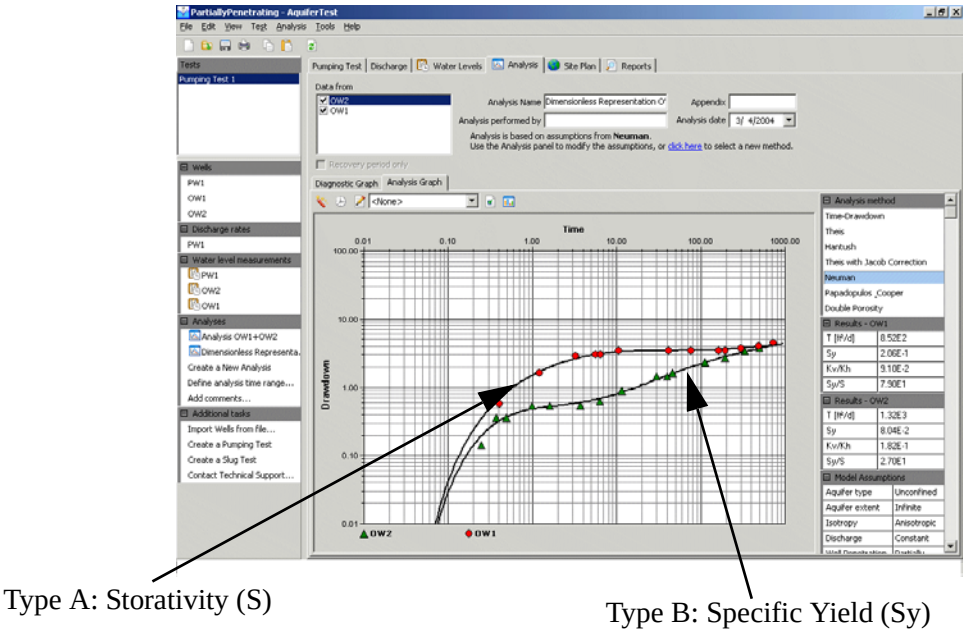
The value of the horizontal hydraulic conductivity can be determined from:

$$K_h = \frac{T}{D}$$

The value of the vertical hydraulic conductivity can be determined from:

$$K_v = \frac{\beta D^2 K_h}{r^2}$$

Two sets of curves are used. Type-A curves are good for early drawdown data when water is released from elastic storage. Type-B curves are good for later drawdown data when the effects of gravity drainage become more significant. The two portions of the type curves are illustrated in the following figure:



In this example, the dimensionless view is shown. An example of a Neuman analysis is available in the project: AquiferTest\Examples\PartiallyPenetratingWells.HYT.

The data requirements for the Neuman Solution are:

- Drawdown vs. time data at an observation well
- Distance from the pumping well to the observation well
- Pumping rate

Dimensionless Parameters

The dimensionless parameters are defined as follows:

$$\beta = \frac{K_z r_D^2}{K_r}$$

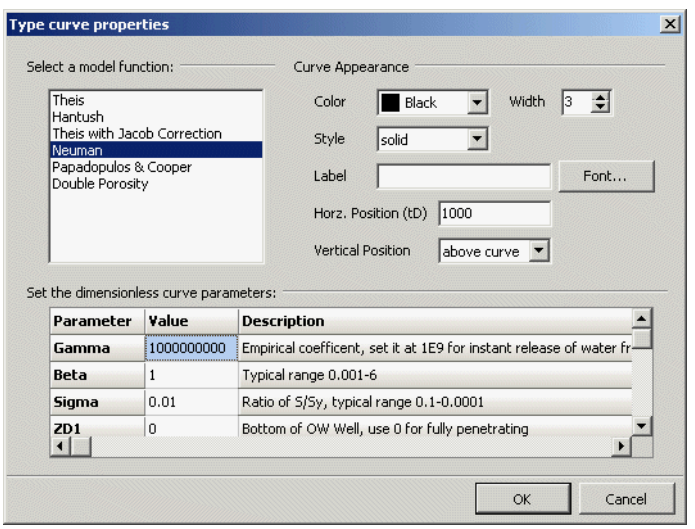
The following factors can be defined in the Type curve options window for the Neuman method:

$$\sigma = \frac{S}{S_y} \quad \gamma = \frac{\alpha_1 D S_y}{K_z} \quad r_D = \frac{r}{D} \quad z_D = \frac{z}{D} \quad l_D = \frac{l}{D} \quad d_D = \frac{d}{D}$$

g = Gamma
α_1: Empirical constant for the drainage from the unconfined zone [T^{-1}]
σ = Sigma, typical range is 0.0001-0.1

where,

K_z: vertical hydraulic permeability
K_r: horizontal hydraulic permeability
r_D: dimensionless distance
r: distance to observation well
D: saturated aquifer thickness
S_y: Usable pore volume



The practical range for the curves are, β= 0.001 to 4.0.

Boulton

Boulton (1963) developed a method for analyzing pumping tests performed in unconfined aquifer (isotropic or anisotropic), which can be used for both fully or partially penetrating wells.

$$s_D = \frac{2\pi T(H-b)}{Q}$$

$$t_D = \frac{Tt}{r^2 S}$$

where H is defined as the average head along the saturated thickness,

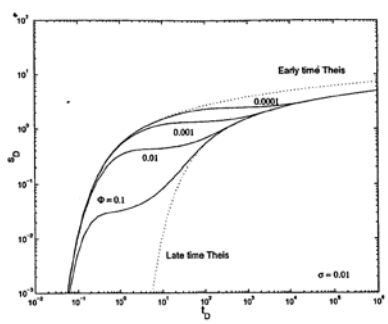
$$H = \frac{1}{b}\int_0^b h\,dz$$

and b = the thickness of the saturated zone

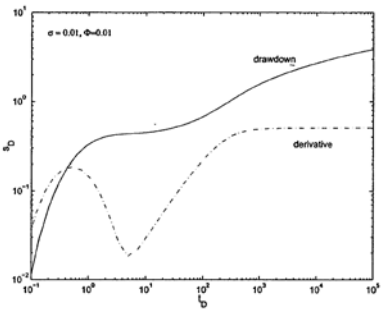
The simplified solution of Boulton can be used to interpret the data. The procedure is as follows:

- Data from the final stages of the test are fitted to a Theis curve. This provides an estimate of T and Sy + S
- Data from the early stages of the test are fitted to a second Theis curve by keeping T and adjusting S. Knowing S one can determine Sy.
- Knowing S and Sy, one can calculate σ and adjust the Boulton type curve. The only remaining unknown being ϕ from which α_1 can be obtained. This later part is not of main interest as α_1 is an empirical parameter without a clear physical signification.

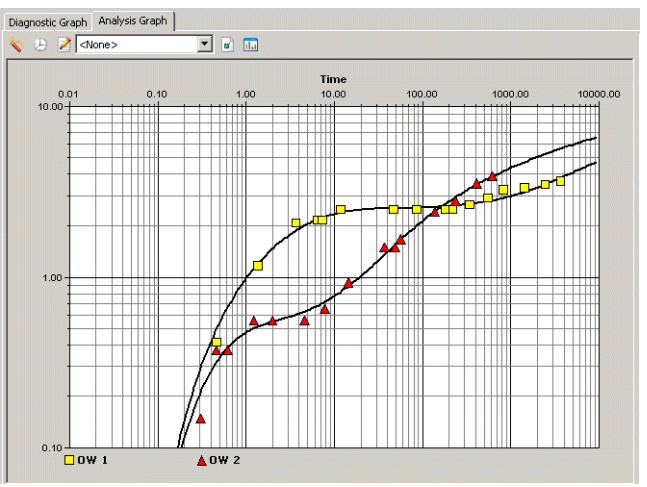
The following image displays the Boulton (1963) type curves for a constant σ



The following image displays a diagnostic plot of Boulton (1963) type curve



An example of a Boulton analysis is shown below:



An example of a Boulton analysis is available in the project: AquiferTest\Examples\Boulton.HYT.

Dimensionless Parameters

The dimensionless parameters are defined as follows:

$$\Phi = \frac{\alpha_1 r^2 S}{T}$$

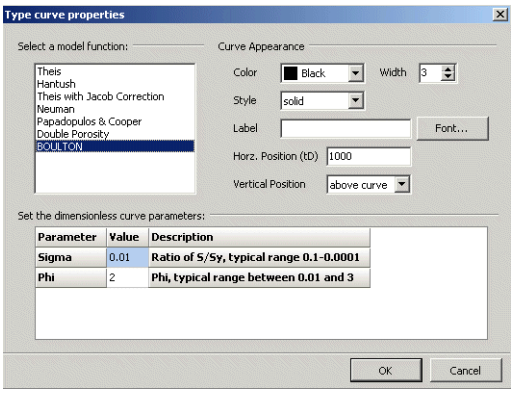
$$\sigma = \frac{S}{S_y}$$

α_1: Empirical constant for the drainage from the unconfined zone [T^{-1}]

σ = Sigma, typical range is 0.0001-0.1

ϕ = Phi, typical range is 0.01-3

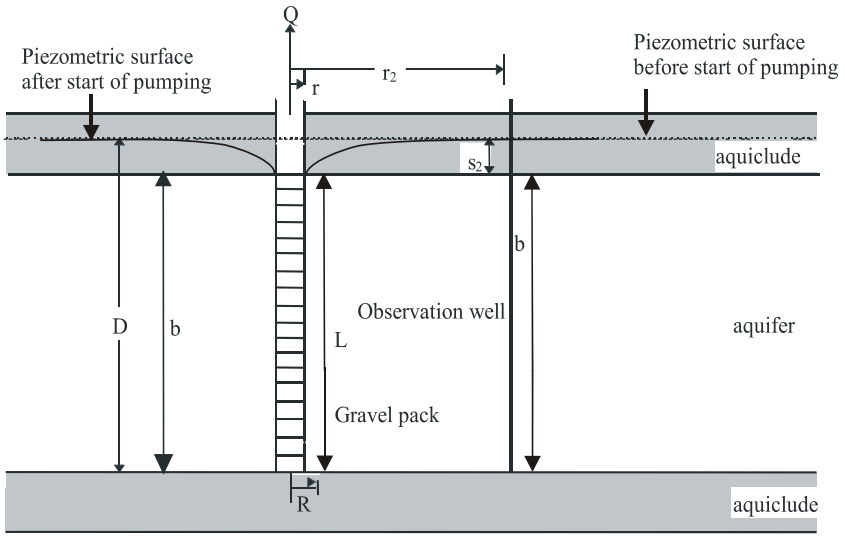
The following factors can be defined in the Type curve options window for the Boulton:



4.7.8 Fracture Flow, Double Porosity

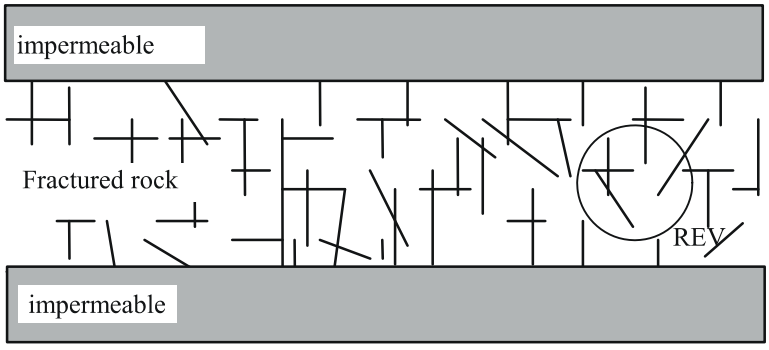
Groundwater flow in a fractured medium can be extremely complex, therefore conventional pumping test solutions methods that require porous flow conditions are not applicable. One approach is to model the aquifer as a series of porous low-permeability matrix blocks separated by hydraulically connected fractures of high permeability: the dual porosity approach. In this case, block-to-fracture flow can be either pseudo-steady-state or transient.

The solutions are appropriate for the conditions shown in the following figure, where the aquifer is confined and D is the thickness of the saturated zone.



If the system is treated as an equivalent porous medium, there is no flow between blocks and fractures. Groundwater travels only in the fractures around the blocks. In this sense, the porosity is the ratio of the volume of voids to the total volume.

Where there is flow from the blocks to the fractures, the fractured rock mass is assumed to consist of two interacting and overlapping continua: a continuum of low-permeability primary porosity blocks, and a continuum of high permeability, secondary porosity fissures (or fractures).



There are two double porosity models used in AquiferTest, which have been widely accepted in the literature. These are the pseudo-steady-state flow (Warren and Root, 1963) and the transient block-to-fracture flow (for example, Kazemi, 1969).

The pseudo-steady-state flow assumes that the hydraulic head distribution within the blocks is undefined. It also assumes that the fractures and blocks within a representative elemental volume (REV) each possess different average hydraulic heads. The magnitude of the induced flow is assumed to be proportional to the hydraulic head difference (Moench, 1984).

Both the Warren Root and Moench (fracture flow with skin) analysis methods are described below.

Warren Root (1963)

AquiferTest uses the pseudo-steady-state double porosity flow model developed by Warren and Root, 1963. The solution states that a fractured aquifer consists of blocks and fissures. For both the blocks (matrix) and the fractures, a hydraulic conductivity, specific storage coefficient and a water level height are defined as follows:

Parameter	Fractures	Matrix (Blocks)
Water Level height	h	h’
Hydraulic conductivity	K_h	K'_h
Specific storage coefficient	S_s	S'_s

The main assumption underlying the double porosity model is that the matrix and the fracture can be considered as two overlapping continuous media (Renard, 2001). In addition, it is also assumed that the water moves from matrix block to fracture, not from block to block or fracture to block; the matrix block serves only as a source of water.

Therefore, the flow equation in the matrix is defined as q_α:

$$-q_\alpha = S'_s \frac{\partial h'}{\partial t}$$

It is often assumed that the flow rate between the matrix and the fractures is proportional to the conductivity of the matrix and to the hydraulic head differences between the two systems.

$$q_\alpha = \alpha k'_h (h' - h)$$

α is a parameter that is dependent on the geometry of the matrix blocks; it has units of L^{-2} (inverse of the square length), and is defined as:

$$\alpha = \frac{A}{lV}$$

with

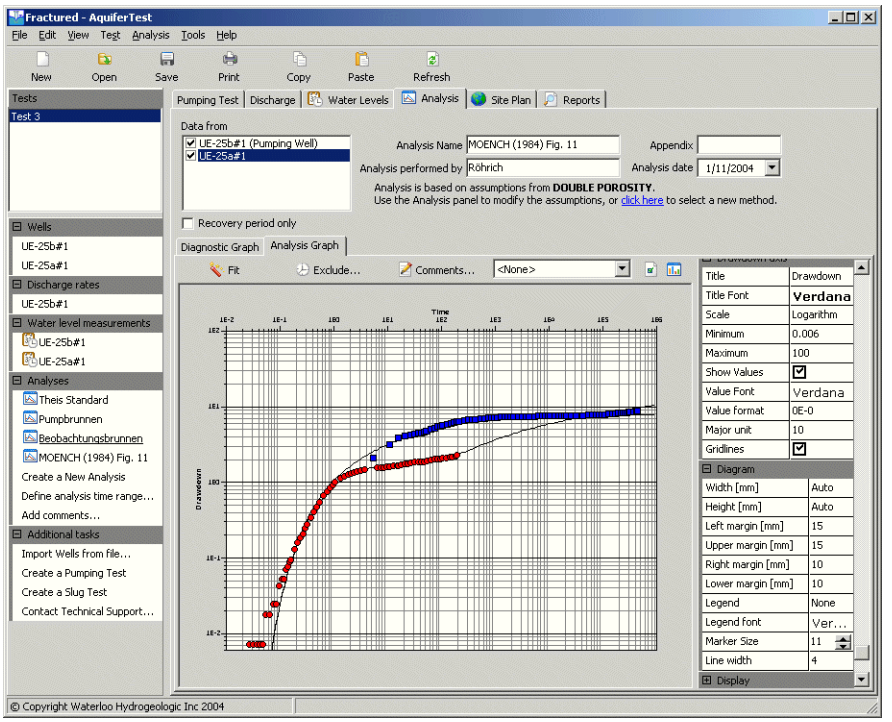
A: Surface of the matrix block

V: Matrix volume

l: characteristic block length

At the beginning of the pumping test, the water is pumped from storage in the fracture system; the matrix blocks does not affect the flow. Midway through, the flow to the well is augmented by water released from the matrix, while the drawdown in the matrix is small compared to drawdown in the fractures. Towards the end of pumping, the drawdown in the matrix approaches the drawdown in the fractures, and the aquifer behaves like a single porosity aquifer with the combined property of the matrix and the fractures (i.e. the drawdown follows the Theis curve).

An example of a Warren Root, Double Porosity analysis graph has been included below:



In this example, the dimensionless view is shown. An example of a Fracture Flow analysis is available in the project: AquiferTest\Examples\Fractured.HYT.

The Warren Root solution requires the following data:

- Drawdown vs. time data at an observation well
- Distance from the pumping well to the observation well
- Pumping rate

Dimensionless parameters

AquiferTest uses the dimensionless parameters, s and L, which characterize the flow from the matrix to the fissures:

$$\Lambda = \frac{\alpha r^2 k_h'}{k_h}$$

$$\sigma = \frac{S_s'}{S_s}$$

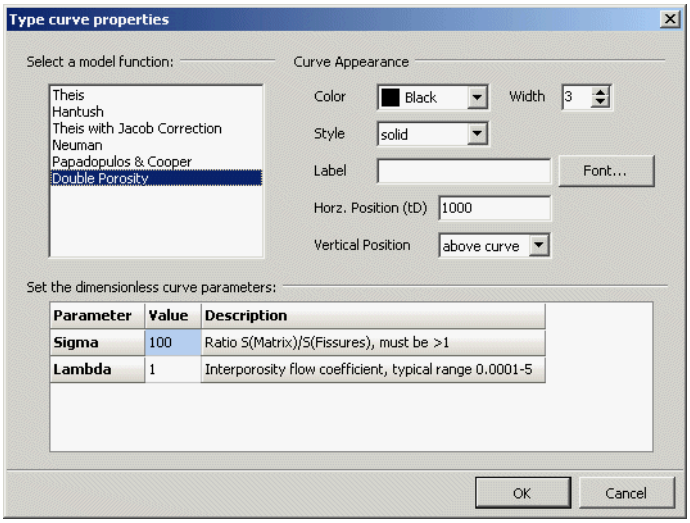
$$r_D = \frac{r}{r_w}$$

with

r_D: dimensionless distance

r: Distance from the pumping well to the observation well

r_w: effective radius of the pumping well, (radius of the well screen)



For a given value of σ, varying Λ (lamda) changes the time at which the flat part of the S (drawdown) starts; the larger this value, the longer is the middle phase of the decreased drawdown and the longer it will take before the drawdown follows the Theis curve.

For a given value of Λ, varying σ changes the time duration of the flat part of the curve (the late time Theis curve is translated horizontally).

Large values of Λ indicate that water will drain from fractures quickly, then originate from the blocks.

A small value of Λ indicates that the transition will be slow.

For more details, please see Kruseman and de Ridder, p. 257.

Moench - Fracture Flow, with Skin

The theory for pseudo-steady-state flow is as follows (Moench, 1984, 1988):

$$t_d = \frac{Kt}{S_s r^2}$$

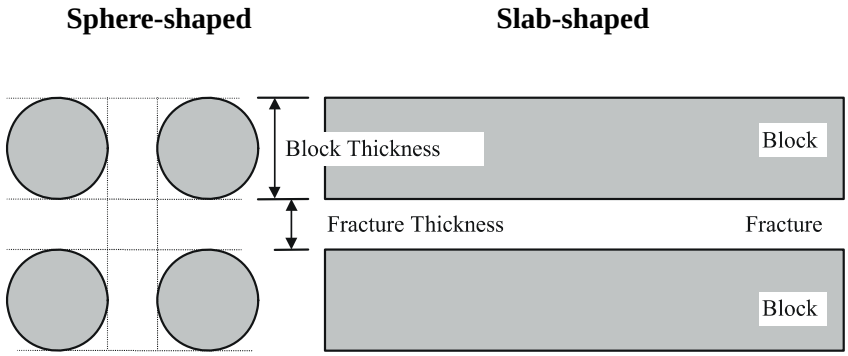
$$h_d = \frac{4\pi KD}{Q}(h_0 - h_f)$$

where h_d is the dimensionless drawdown, and t_d is the dimensionless time.

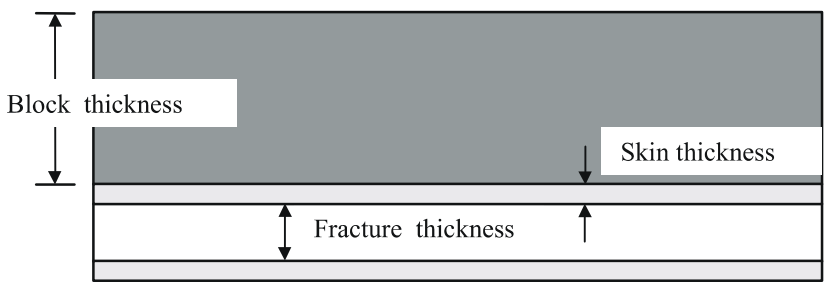
The initial discharge from models using the pseudo-steady-state flow solution with no well-bore storage is derived primarily from storage in the fissures. Later, the fluid will be derived primarily from storage in the blocks. At early and late times, the drawdown should follow the familiar Theis curves.

For transient block to fissure flow, the block hydraulic head distribution (within an REV) varies both temporally and spatially (perpendicular to the fracture block interface). The initial solution for slab-shaped blocks was modified by Moench (1984) to support sphere-shaped blocks. Well test data support both the pseudo-steady-state and the transient block-to-fracture flow solutions.

For transient block-to-fracture flow, the fractured rock mass is idealized as alternating layers (slabs or spheres) of blocks and fissures.



Moench (1984) uses the existence of a fracture skin to explain why well test data support both the pseudo-steady-state and transient block-to-fracture flow methods. The fracture skin is a thin skin of low permeability material deposited on the surface of the blocks, which impedes the free exchange of fluid between the blocks and the fissures.



If the fracture skin is sufficiently impermeable, most of the change in hydraulic head between the block and the fracture occurs across the fracture skin and the transient block-to-fracture flow solution reduces to the pseudo-steady-state flow solution.

The fracture skin delays the flow contributions from the blocks, which results in pressure responses similar to those predicted under the assumption of pseudo-steady state flow as follows:

$$h_{wD} = \frac{4\pi KH}{Q_T}(h_t - h_w)$$

$$h'_D = \frac{4\pi KH}{Q_T}(h_i - h')$$

where h_{wD} is the dimensionless head in the pumping well, and h'_D is the dimensionless head in the observation wells.

With both the pseudo-steady-state and transient block-to-fracture flow solutions, the type curves will move upward as the ratio of block hydraulic conductivity to fracture hydraulic conductivity is reduced, since water is drained from the blocks faster.

With the fracture flow analysis, you can also plot type curves for the pumping wells. However, for pumping wells it may be necessary to consider the effects of well bore storage and well bore skin. If the well bore skin and the well bore storage are zero, the solution is the same as the Warren and Root method (1963). The equations for well bore storage are as follows:

$$W_D = \frac{C}{2\pi r^2 S}$$

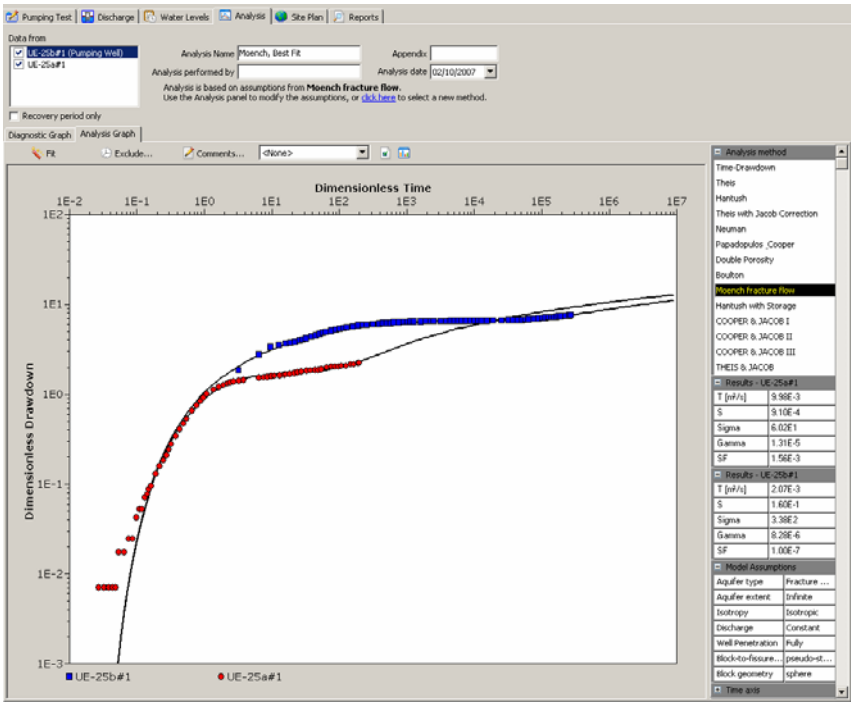
where:

$C=\pi R^2$ (for changing liquid levels) **or**
$C=V_w\rho_w g C_{obs}$

where V_w is volume of liquid in the pressurized section, ρ_w is the density, g is the gravitational constant, C_{obs} is the observed compressibility of the combined fluid-well system, and S is the calculated storativity.

This solution, however, is iterative. If you move your data set to fit the curve, your storativity will change which in turn alters your well bore storage.

An example of a Moench Fracture Flow analysis graph has been included in the following figure:



An example of a Moench Fracture Flow analysis is available in the project: AquiferTest\Examples\Moench Fracture Skin.HYT

The following table illustrates a comparison of the AquiferTest results, to those published in Moench,1984.

	AquiferTest 4.2	**Published (Moench, 1984)**
T	4.00E-3	4.00E-3
S	6.00E-4	6.00E-4
Sigma	2.00E2	2.00E2
Gamma	1.40E-3	1.40E-3
SF	1.00	1.00

The Moench Solution for fracture flow assumes the following:

- The aquifer is anisotropic and homogeneous
- The aquifer is infinite in horizontal extent
- The aquifer is of constant thickness

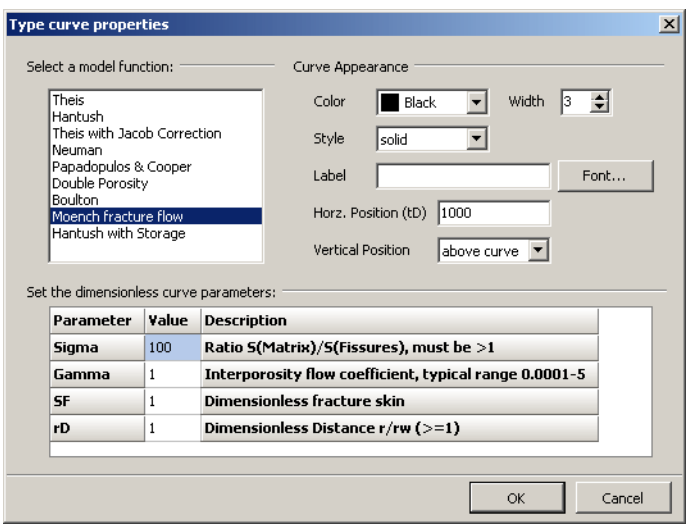
- The aquifer is confined above and below by impermeable layers
- Darcy's law is valid for the flow in the fissures and blocks
- Water enters the pumped well only through the fractures
- Observation piezometers reflect the hydraulic head of the fractures in the REV
- Flow in the block is perpendicular to the block-fracture interface
- The well is pumped at a constant rate
- Both the pumping well and the observation wells are fully penetrating

The model assumptions must be defined in the Analysis Panel, as shown below:

Model Assumptions	
Aquifer type	Fracture Skin
Aquifer extent	Infinite
Isotropy	Isotropic
Discharge	Constant
Well Penetration	Fully
Block-to-fissure flow model	transient
Block geometry	slab

For the block-to-fissure flow model, select either **transient** or **pseudo-steady state**. For the block geometry, select either **slab** or **sphere**.

Dimensionless Parameters



The dimensionless parameters are defined below:

Sigma: must be > 1

$$\sigma = \frac{S_s^{'}}{S_s}$$

Gamma: Interporosity flow coefficient, typical range 0.0001-5

$$\gamma = \left(\frac{r_w}{b'}\right)\left(\frac{K'}{K}\right)^{\frac{1}{2}}$$

Dimensionless Distance: typical value, >=1

$$r_D = \frac{r}{r_w}$$

Dimensionless fracture skin:

$$SF = \frac{K' b_s}{K_s b'}$$

4.7.9 Single Well Analysis with Well Effects

Measuring Drawdown in the Well

Quite often project budget restrictions prevent the installation of an observation well or piezometer at the site. As such, the pumping test must be conducted with a single pumping well, and the drawdown measurements must be observed at this well.

The drawdown in the pumping well is affected however not only by the aquifer characteristics, but also influenced by the following factors:

- Well storage
- Well Skin effects
- Well Losses

With a single well analysis, the storage coefficient may not be determined, or the value that is calculated may not accurately and reliably represent the actual site conditions.

When doing a single well analysis, it is recommended to use a solution method that accounts for well bore storage. The Papadopulos-Cooper method available in **AquiferTest** accounts for these well effects.

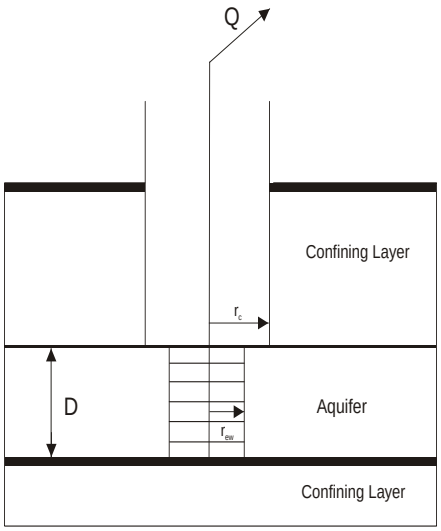
4.7.10 Large Diameter Wells with WellBore Storage - Papadopulos-Cooper

Standard methods of aquifer data analysis assume storage in the well is negligible; however, for large-diameter wells this is not the case. At the beginning of the pumping test, the drawdown comes not only from the aquifer, but also from within the pumping well itself, or from the annular space surrounding the well (i.e. the gravel/filter pack).

Thus the drawdown that occurs is reduced compared to the standard Theis solution. However, this effect becomes more negligible as time progresses, and eventually there is no difference when compared to the Theis solution for later time drawdown data.

Papadopulos devised a method that accounts for well bore storage for a large-diameter well that fully penetrates a confined aquifer (Kruseman and de Ridder, 1990). Using the Jacob Correction factor, this method can also be applied to unconfined aquifers.

The diagram below shows the required conditions for a large-diameter well:



where,

D: initial saturated aquifer thickness

r_{ew}: effective radius of the well screen or open hole

r_c: radius of the unscreened portion of the well over which the water level is changing

The mathematical model for the solution is described in Papadopulos & Cooper (1967). The drawdown in the pumping well (r=rw) is calculated as follows:

$$s_w(t) = \frac{Q}{4\pi T} F\left(\frac{Tt}{r_w^2 S}, \alpha\right)$$

with

$$\alpha = \frac{r_w^2 S}{r_c^2} = \frac{1}{2C_D}$$

s_w: drawdown in the pumping well

r_{ew}: effective radius of the filter/well

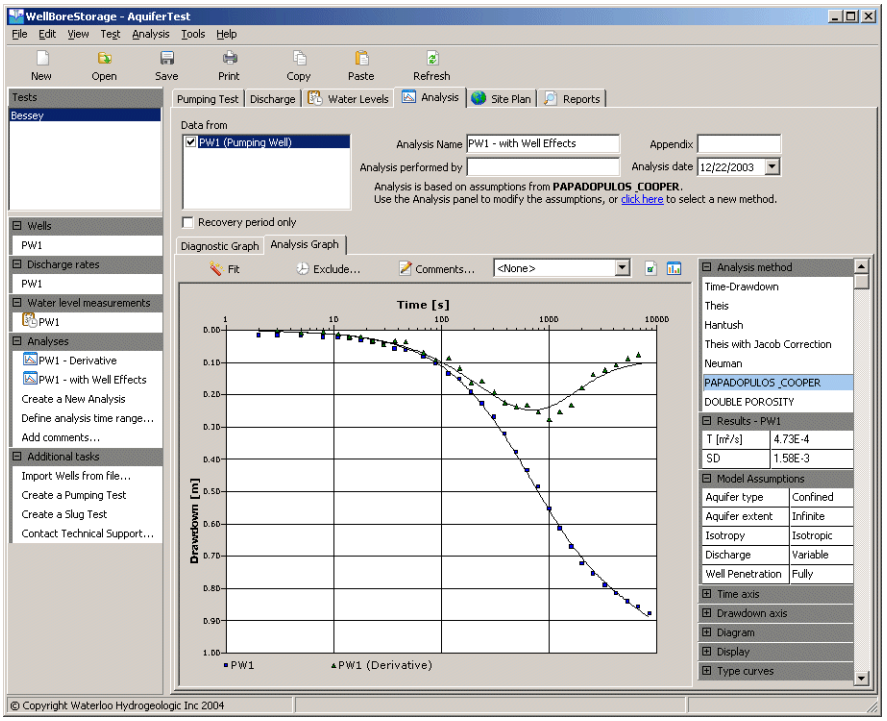
r_c: radius of the full pipe, in which the water level changes

C_D: dimensionless well storage coefficient. For the Papadopulos method, the symbol α is used.

As shown in the above equations, the well storage coefficient C_D correlates with the storage coefficient S.

If only early time-drawdown data are available, it will be difficult to obtain a match to the type curve because the type curves differ only slightly in shape. The data curve can be matched equally well with more than one type curve. Moving from one type curve to another results in a value of S (storativity) that differs an order of magnitude. For early time data, storativity determined by the Papadopulos curve-fitting method is of questionable reliability. (Kruseman and de Ridder, 1990)

An example of a Papadopulos-Cooper Solution graph has been included in the following figure:

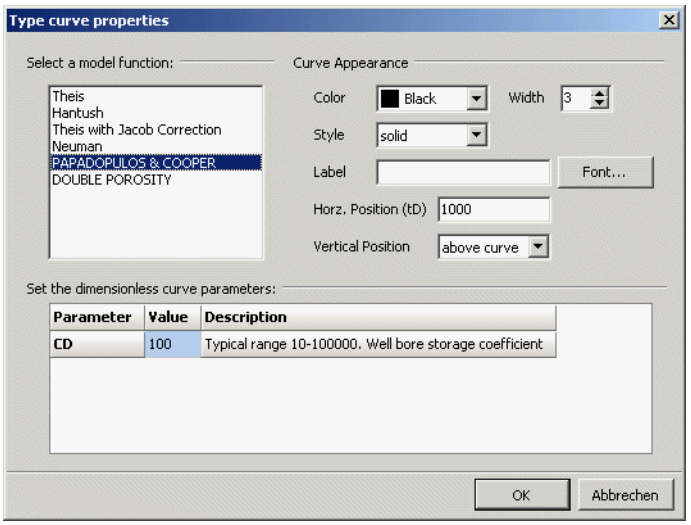


An example of a Papadopulos - Cooper analysis is available in the project: AquiferTest\Examples\WellBoreStorage.HYT.

Data requirements for the Papadopulos-Cooper solution are:

- Time vs. Drawdown data at a pumping well
- Pumping well dimensions
- Pumping rate

Dimensionless Parameters



For Papadopulos the dimensionless curve parameter S_D is defined as.

$$S_D = \frac{1}{2C_D}\frac{r_c^2}{r_w^2}$$

with

r_c: Radius of the full pipe in that the water level changes

r_w: Radius of the screen

Using Effective Well Radius

The effective radius of the well typically lies somewhere between the radius of the filter and the radius of the borehole (i.e. it is a calculated value). The exact value depends on the usable pore volume of the filter pack.

In **AquiferTest**, the following values are defined in the wells table.

B: Radius of the borehole

R: Radius of the screen

r: Radius of the riser pipe (casing)

n: Effective porosity of the annular space (gravel/sand pack)

Though not specifically indicated, **AquiferTest** uses the value R (i.e. screen radius) as effective radius; however, if the option to "use effective well radius (use r(w))" is selected in the Wells table, **AquiferTest** computes this value according to the formula

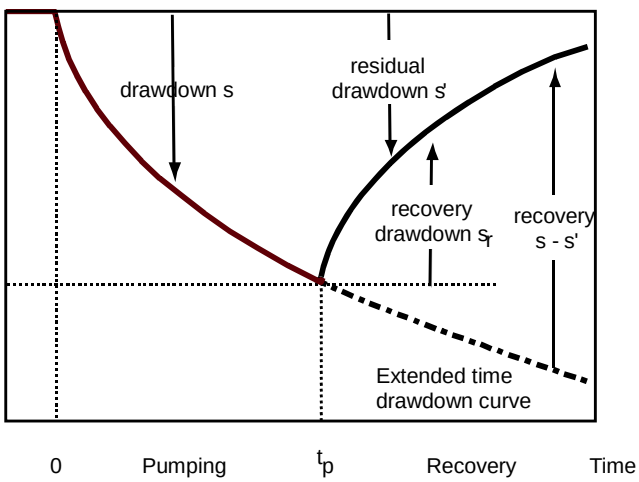
$$r_w = \sqrt{R^2(1-n) + nB^2}$$

4.7.11 Recovery Analysis - Agarwal Solution (1980)

When the pump is shut down after a pumping test, the water level inside the pumping and observation wells begin to rise. This rise in water level is known as recovery drawdown (s'). Recovery-test measurements allow the Transmissivity of the aquifer to be calculated, thereby providing an independent check on the results of the pumping test.

Recovery drawdown data can be more reliable than drawdown data because the recovery occurs at a constant rate, whereas constant discharge pumping is often difficult to achieve in the field. Recovery drawdown data can be collected from both the pumping and observation wells.

Agarwal (1980) proposed a method to analyze recovery data with interpretation models developed for the pumping period. The method is based on defining a recovery drawdown s_r and replacing the time axis, during the recovery, by an equivalent time t_e.



Agarwal defines the recovery drawdown s_r as the difference between the head h at any time during the recovery period and the head h_p at the end of the pumping period.

$$s_r = h - h_p$$

The recovery time t_r is the time since the recovery started. It is related to the time t since pumping started and to the total duration of pumping t_p.

$$t_r = t - t_p$$

If we consider the case of the recovery after a constant rate pumping test, the head h in the aquifer can be expressed with the Theis solution or can be approximated by the Cooper-Jacob expression. Using the Cooper-Jacob expression, Agarwal expresses the recovery drawdown as:

$$s_r = \frac{Q}{4\pi T}\left[\ln\frac{4Tt_p}{r^2S} - \ln\frac{4T(t_r + t_p)}{r^2S} + \ln\frac{4Tt_r}{r^2S}\right]$$

or

$$s_r = \frac{Q}{4\pi T}\ln\left(\frac{4T}{r^2S}\frac{t_r\ t_p}{(t_r + t_p)}\right) = \frac{Q}{4\pi T}\ln\left(\frac{4Tt_e}{r^2S}\right)$$

with t_e the equivalent Agarwal time:

$$t_e = \frac{t_r\ t_p}{(t_r + t_p)}$$

The expression of the recovery drawdown in this case is identical to the Cooper-Jacob expression if one replaces the usual time by the equivalent Agarwal time t_e.

In the case of n successive pumping periods: with constant rate q_1 for t=0 to $t=t_1$, constant rate q_2 for $t=t_1$ to t_2, etc., the same result is obtained:

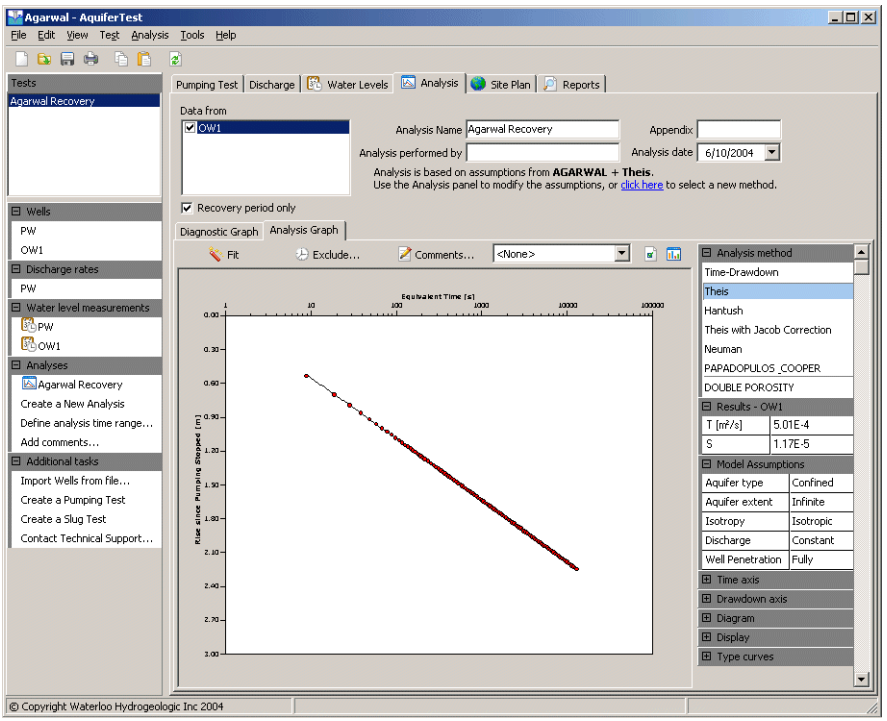
$$s_r = \frac{q_n}{4\pi T}\ln\left(\frac{4Tt_e}{r^2S}\right)$$

with an equivalent Agarwal time defined by:

$$t_e = \left[\Pi_{j=1}^{n} \left(\frac{t_n - t_{j-1}}{t_r + t_n - t_{j-1}} \right)^{\left(\frac{q_j - q_{j-1}}{q_n} \right)} \right] t_r$$

with $t_0 = 0$ and $q_0 = 0$, and t_r the time since the beginning of the recovery.

An example of a Agarwal Recovery analysis graph has been included below:



In this example, only the recovery data is displayed. An example of an Agarwal recovery solution is available in the project: AquiferTest\Examples\Agarwal-Recovery.HYT.

The data requirements for the Recovery Solution are:

- Recovery vs. time data at a pumping or observation well
- Distance from the pumping well to the observation well
- Pumping rate and duration

The Recovery solution can be applied to any standard pumping test method.

You **must** enter the pumping duration in the **Discharge** tab, and specify the pumping rate as variable. If you entered measurements since the beginning of pumping, select the **"Recovery Period only"** option, to analyze only the data recorded after pumping was stopped. This check box is located directly above the Analysis graph.

You may enter recovery data only in the **Water Levels** tab, however, you still need to define the pumping rate information.

Assumptions and Domain of Validity

Agarwal (1980) derived rigorously the previous expressions under the assumptions of a two dimensional radial convergent flow field, in an infinite confined aquifer, with a fully penetrating well, with or without skin effect, and no well-bore storage. It assumes also that the Cooper-Jacob approximation is valid (late time asymptote).

Agarwal shows empirically that the method is valid for a single well test with well bore storage and skin effect when the pumping time is large.

$$t_p > \left(30 + \frac{7}{4}\sigma\right)\frac{r_c^2}{T}$$

where:

T = Transmissivity
r_c = Casing radius if different from the screen radius
σ = Skin factor

In addition, Agarwal demonstrates that the method provides good results for vertically fractured wells with infinite and finite flow capacity fracture (Gringarten et al. solution).

Reference

Agarwal, R.G., 1980. A new method to account for producing time effects when drawdown type curves are used to analyze pressure buildup and other test data.

Proceedings of the 55th Annual Fall Technical Conference and Exhibition of the Society of Petroleum Engineers. Paper SPE 9289.

4.8 Well Performance Methods

4.8.1 Specific Capacity

This test is commonly used to evaluate over time the productivity of a well, which is expressed in terms of its *specific capacity*, C_s. Specific capacity is defined as:

$$C_s = \frac{Q}{\Delta h_w}$$

where,

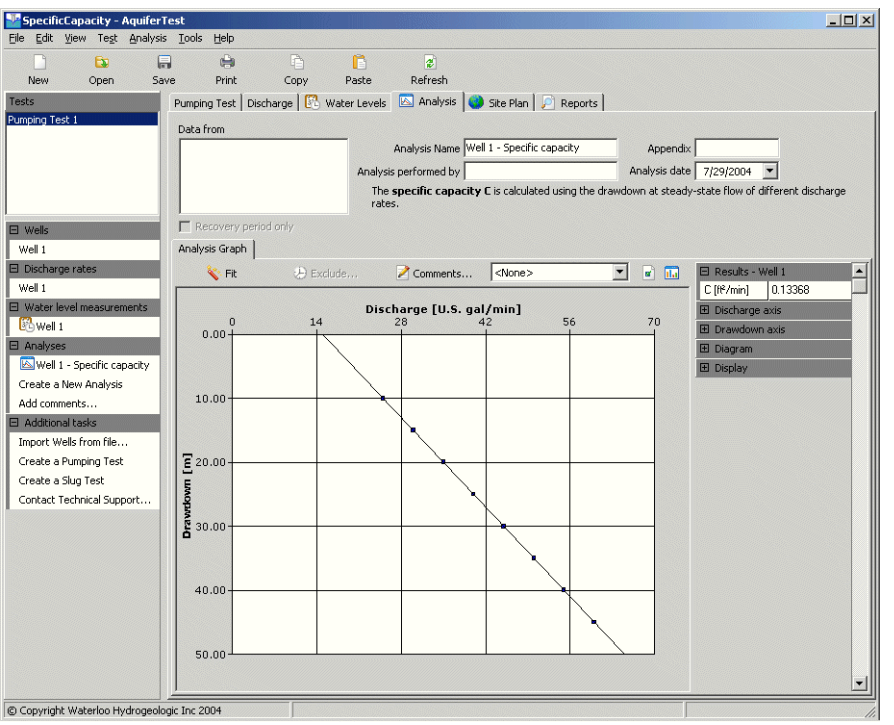
Q = pumping rate

Δh_w = drawdown in the well due to both aquifer drawdown and well loss.

Well loss is created by the turbulent flow of water through the well screen and into the pump intake. The results of testing are useful to track changes in well yield over time, or to compare yields between different wells.

Specific capacity is estimated by plotting discharge on a linear X axis and drawdown on a linear Y axis, and measuring the slope of the straight line fit.

An example of a Specific Capacity test has been included in the following figure:



An example of a Specific Capacity analysis is available in the project: AquiferTest\Examples\SpecificCapacity.HYT.

The units for the specific capacity measurement are the following:

Pumping rate (units) per distance (ft or m) of drawdown. For example:

$$\frac{\frac{ft^3}{s}}{ft}$$

which becomes....

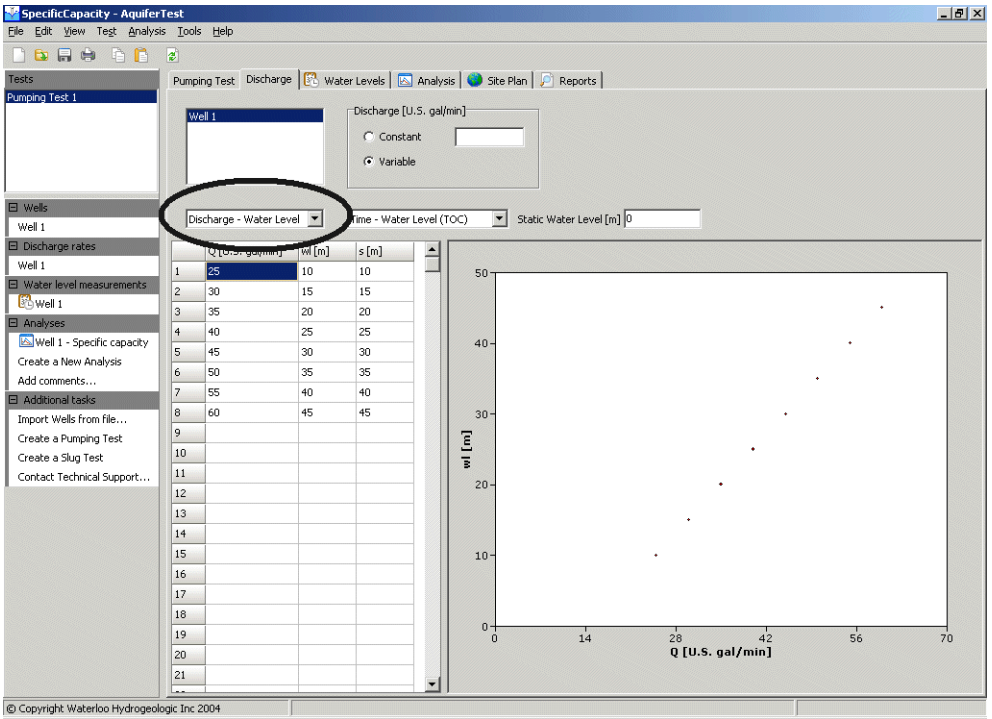
$$\frac{ft^2}{s}$$

The Specific Capacity test assumes the following:

- The well is pumped at a constant rate long enough to establish an equilibrium drawdown
- Drawdown within the well is a combination of the decrease in hydraulic head (pressure) within the aquifer, and a pressure loss due to turbulent flow within the well

The data requirements for the Specific Capacity test are:

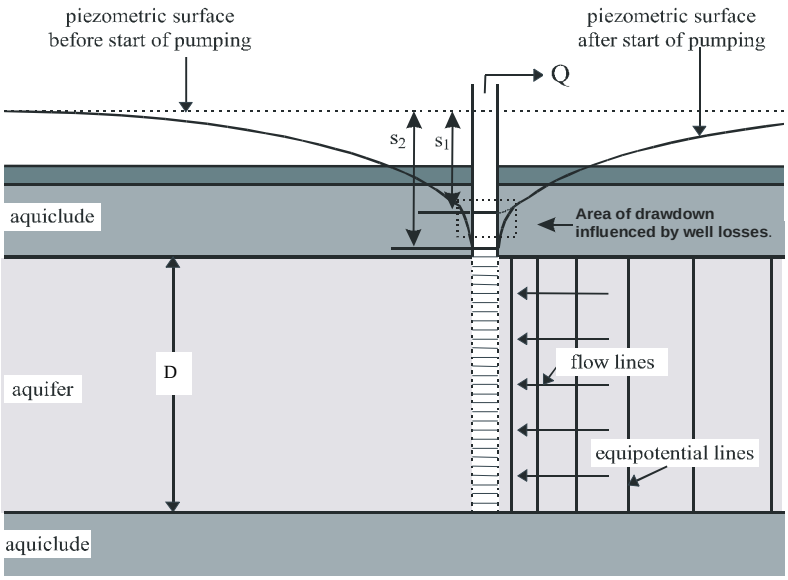
- Pumping well geometry
- Drawdown vs. discharge rate data for the pumping well. This data is entered in the Discharge tab, as shown below.



4.8.2 Hantush-Bierschenk Well Loss Solution

The Hantush-Bierschenk Well Loss Solution is used to analyze the results of a variable rate “step test” to determine both the linear and non-linear well loss coefficients B and C. These coefficients can be used to predict an estimate of the real water level drawdown inside a pumping well in response to pumping. Solution methods such as Theis (1935) permit an estimate of the theoretical drawdown inside a pumping well in response to pumping, but do not account for linear and non-linear well losses which result in an increase in drawdown inside the well. Quite often, these non-linear head losses are caused by turbulent flow around the pumping well (Kruseman and de Ridder, 1990).

The solution is appropriate for the conditions shown in the following figure, where the aquifer is confined and D is the thickness of the saturated zone.



The figure above illustrates a comparison between the theoretical drawdown in a well (S1) and the actual drawdown in the well (S2) which includes the drawdown components inherent in S1 but also includes additional drawdown from both the linear and non-linear well loss components.

The general equation for calculating drawdown inside a pumping well that includes well losses is written as:

$$s_w = BQ + CQ^p$$

where,

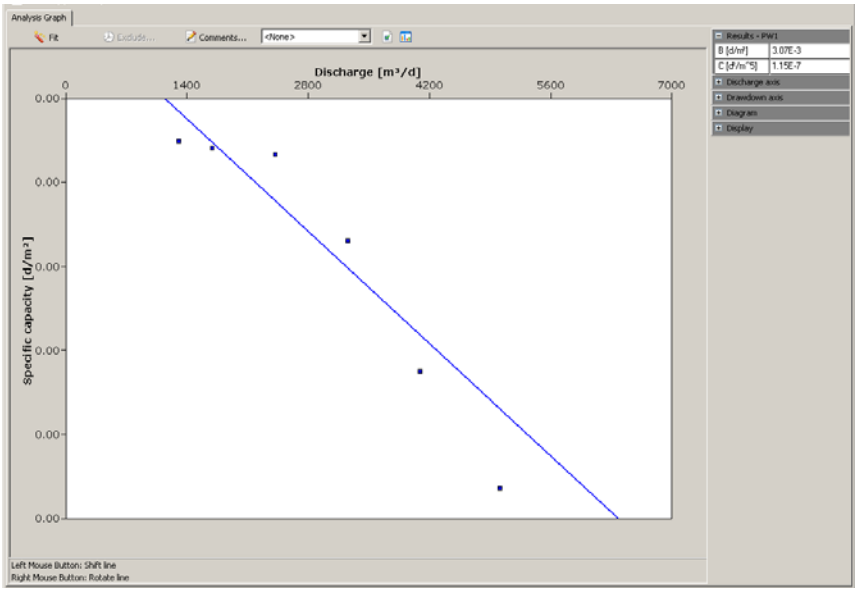
s_w = drawdown inside the well
B = linear well-loss coefficient
C = non-linear well-loss coefficient
Q = pumping rate
p = non-linear well loss fitting coefficient

p typically varies between 1.5 and 3.5 depending on the value of Q; Jacob proposed a value of p = 2 which is still widely used today (Kruseman and de Ridder, 1990).

AquiferTest calculates a value for the well loss coefficients **B** and **C** which you can use in the equation shown above to estimate the expected drawdown inside your pumping well for any realistic discharge Q at a certain time t (B is time dependent). You can then use the relationship between drawdown and discharge to choose, empirically, an

optimum yield for the well, or to obtain information on the condition or efficiency of the well.

An example of a Hantush-Bierschenk Well Loss analysis graph has been included below:



An example of a Hantush-Bierschenk analysis is available in the project: AquiferTest\Examples\Hantush Bierschenk2.HYT

The table below illustrates a comparison of the results, with those published in Kruseman and de Ridder,1990.

	AquiferTest 4.2	**Published:** Kruseman and de Ridder, 1990
B	3.07E-3	3.26E-3
C	1.15E-7	1.45E-7

The Hantush-Bierschenk Well Loss Solution assumes the following:

- The aquifer is confined, leaky, or unconfined
- The aquifer has an **apparent** infinite extent
- The aquifer is homogeneous, isotropic, and of uniform thickness over the area influenced by pumping
- The piezometric surface was horizontal prior to pumping
- The aquifer is pumped step-wise at increased discharge rates
- The well is fully penetrating
- The flow to the well is in an unsteady state

The data requirements for the Hantush-Bierschenk Well Loss Solution are:

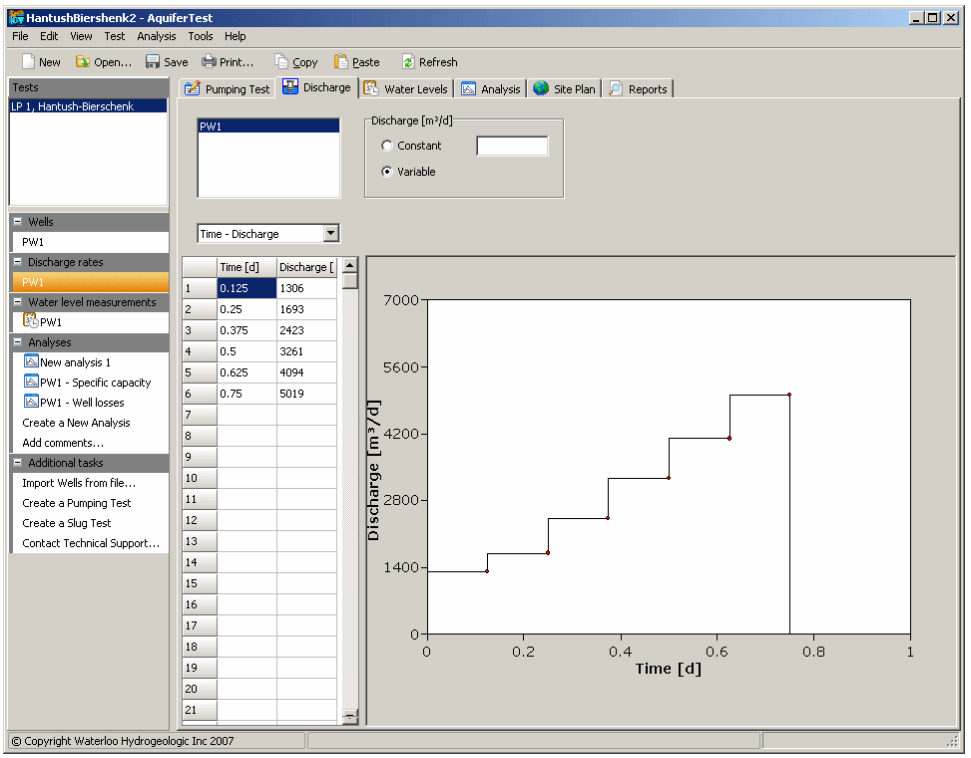
- Time-drawdown data from the pumping well
- Time-discharge data for at least three equal duration pumping sessions

Using the Hantush-Bierschenk Well Loss Solution is simply a matter of formatting the data correctly. The table below illustrates the pumping time and discharge rates for the example project (Hantush Bierschenk2.HYT).

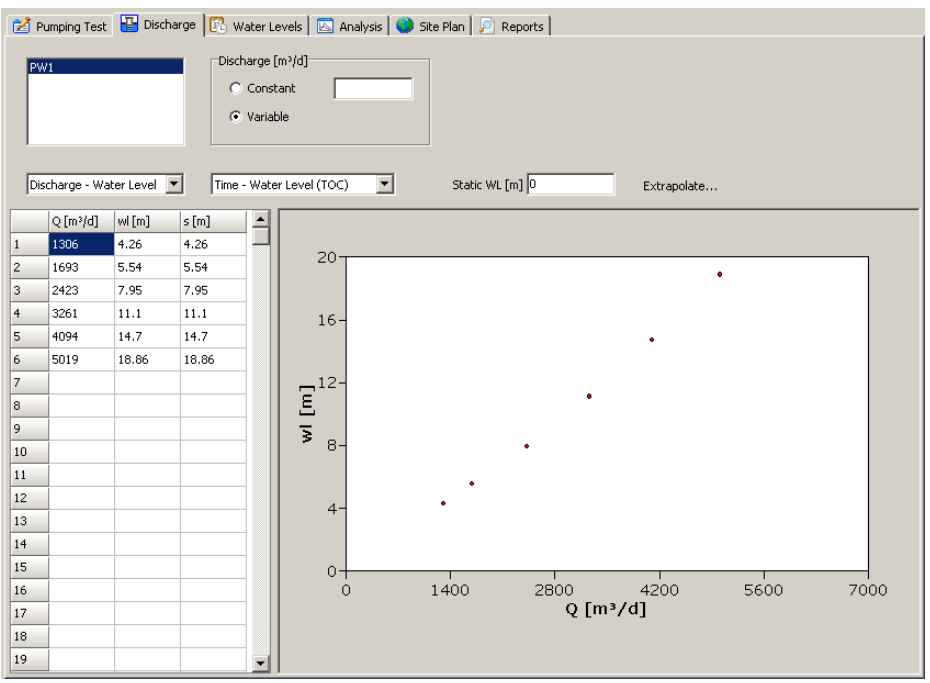
Time (min.)	**Discharge (m^3/d)**
180	1306
360	1693
540	2423
720	3261
900	4094
1080	5019

When you enter your time-discharge data in AquiferTest, your first entry is the initial pumping rate. Using the table above as an example, the pumping rate from 0-180 minutes was 1306 m^3/day. The second pumping rate from 180-360 minutes was 1693 m^3/day, and so on.

The figure below shows the data entered in the Time-Discharge table.

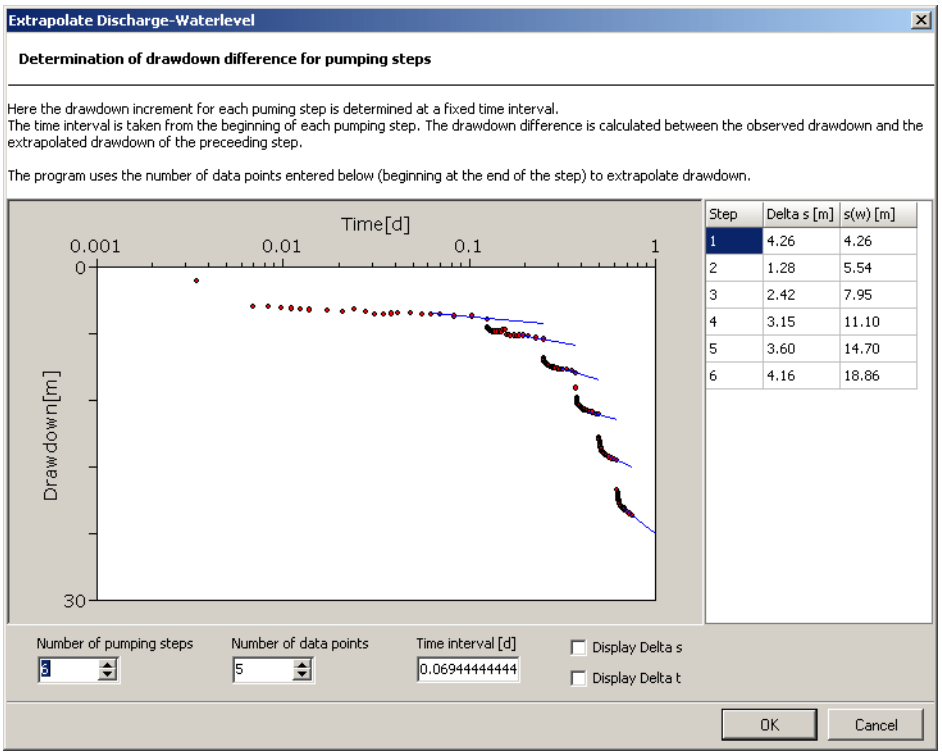


If steady-state flow is reached in each step, enter the discharge-water level data in the Discharge-Waterlevel table, as shown in the image below.



Alternatively, for a step-test where flow is at an unsteady-state, click on the **Extrapolate...** button to extrapolate the discharge-water level values from the time-drawdown data.

Upon selecting, the **Extrapolate Discharge-Waterlevel** dialog will open, as shown below.


Extrapolate Discharge-Waterlevel
Determination of drawdown difference for pumping steps
Here the drawdown increment for each puming step is determined at a fixed time interval.
The time interval is taken from the beginning of each pumping step. The drawdown difference is calculated between the observed drawdown and the extrapolated drawdown of the preceeding step.
The program uses the number of data points entered below (beginning at the end of the step) to extrapolate drawdown.
Time[d]
0.001
0.01
0.1
1
0
30
Drawdown[m]
Step
Delta s [m]
s(w) [m]
1 4.26 4.26
2 1.28 5.54
3 2.42 7.95
4 3.15 11.10
5 3.60 14.70
6 4.16 18.86
Number of pumping steps
3
Number of data points
5
Time interval [d]
0.06944444444
Display Delta s
Display Delta t
OK
Cancel

This dialogue allows you to edit the number of steps to include in the analysis, as well as the line-fitting parameters for each step.

Each step in the analysis corresponds to a pumping rate entered in the pumping test tab. In the example above, there are six pumping rates in the test which therefore allows a maximum of six steps in the analysis.

The time-drawdown data is plotted on a semi-log graph, and the slope of each line is determined based on the **Number of data points** you specify. Selection of data points begins at the end of the step and progresses backward in time as you add more points for the line slope calculation. For example, if the number of points is equal to five then AquiferTest will use the last five data points in each step to calculate the slope.

The **Time Interval** is the time from the beginning of each step at which the change in drawdown (Δs) for each step is measured. The point of time for calculating Δs is calculated as follows:

$$t_i + \Delta t = t_{ds}$$

where:

- t_i = starting time of step
- Δt = the specified time interval
- t_{ds} = calculation point for Δs

This measurement point is essential as the difference in drawdown is calculated between each step. The selection of the time interval is left to the discretion of the user.

AquiferTest then uses the drawdown differences and the specified time interval to produce two coefficients: **B** (linear well loss coefficient) and **C** (non-linear well loss coefficient). These coefficients can be used to estimate the expected drawdown inside your pumping well for a realistic discharge (Q) at a certain time (t). This relationship can allow you to select an optimum yield for the well, or to obtain information on the condition or efficiency of the well.

Finally, the **Number of pumping steps** allows you to edit the number of steps (i.e. changes in the discharge rate) to use in the discharge versus drawdown plot. You should have a minimum of three steps specified to assist in obtaining a good fit of the line to the analysis plot.

Once the extrapolation settings have been defined, click **[Ok]** to accept the drawdown values. To select the analysis method, from the main menu, go to **Analysis \ Pumping Well Analysis \ Well Losses.**

For more information on the Hantush-Bierschenk Well Loss solution, please refer to a pumping test reference such as Kruseman and de Ridder (1990).

4.9 Slug Test Solution Methods

In a slug test, a solid “slug” is lowered into the piezometer, instantaneously raising the water level in the piezometer. The test can also be conducted in the opposite manner by instantaneously removing a “slug” or volume of water (bail test).

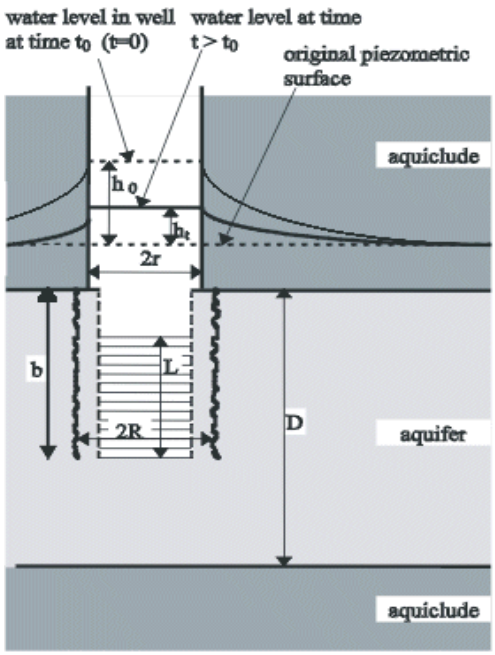
With the slug test, the portion of the aquifer “tested” for hydraulic conductivity is small compared to a pumping test, and is limited to a cylindrical area of small radius (*r*) immediately around the well screen.

AquiferTest provides three slug test analysis methods:

- Bouwer & Rice
- Hvorslev
- Cooper-Bredehoeft-Papadopulos

4.9.1 Bouwer-Rice Slug Test

The Bouwer-Rice (1976) slug test is designed to estimate the hydraulic conductivity of an aquifer. The solution is appropriate for the conditions shown in the following figure.



Bouwer-Rice (1976) developed an equation for hydraulic conductivity as follows:

$$K = \frac{r^2 \ln\left(\frac{R_{cont}}{R}\right)}{2L} \cdot \frac{1}{t} \cdot \ln\left(\frac{h_o}{h_t}\right)$$

where:

r = piezometer radius (or r_{eff} if water level change is within the screened interval)

R = radius measured from centre of well to undisturbed aquifer material

R_{cont} = contributing radial distance over which the difference in head, h_0, is dissipated in the aquifer

L = the length of the screen

b = length from bottom of well screen to top of the aquifer

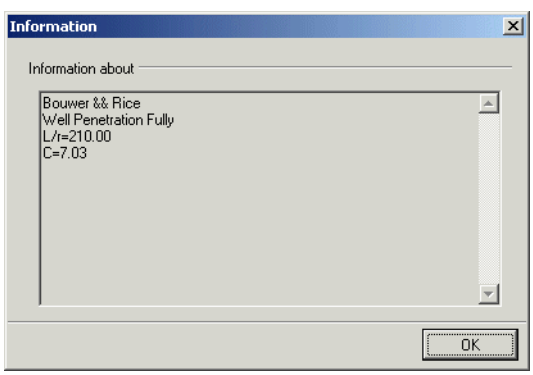
h_t = displacement as a function of time (h_t/h_0 must always be less than one, i.e. water level must always approach the static water level as time increases)

h_0 = initial displacement

Since the contributing radius (R_{cont}) of the aquifer is seldom known, Bouwer-Rice developed empirical curves to account for this radius by three coefficients (A,B,C) which are all functions of the ratio of L/R. Coefficients A and B are used for partially penetrating wells, and coefficient C is used only for fully penetrating wells.

To analyze partially penetrating wells, select the "**Partially**" Penetration option in the Wells table.

The calculated coefficient values can be displayed for a Bouwer & Rice analysis by pressing **Ctrl-Alt-D** (NOT **Ctrl-Alt-Del**). An example of the information window is shown below:



The data are plotted with time on a linear X axis and h_t/h_o on a logarithmic Y axis.

The effective piezometer radius, r, should be specified as the radius of the piezometer, unless the water level falls within the screened portion of the aquifer during the slug test.

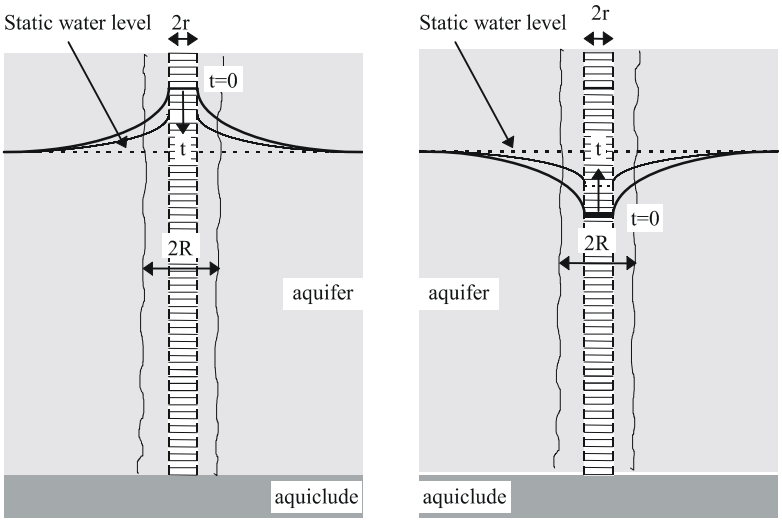
If the water level is in the well screen, the effective radius may be calculated as follows:

$$r_{eff} = \left[r^2(1-n) + nR^2\right]^{1/2}$$

where *n* is the porosity of the gravel pack around the well screen.

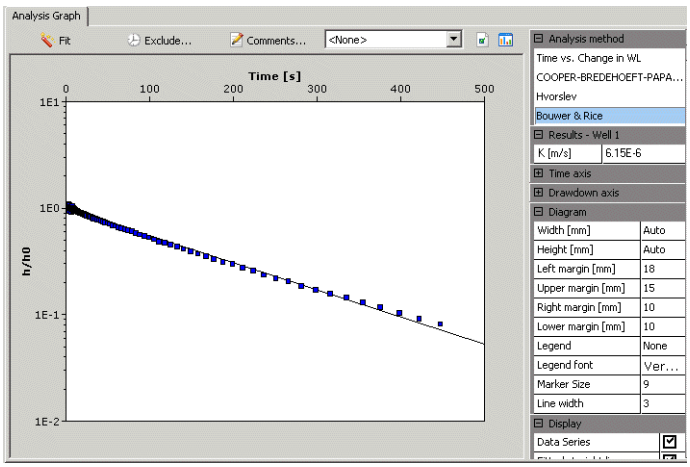
r_{eff} is the same as r(w), which is defined in the **Wells** table.

Slug Test **Bail Test**



In cases where the water level drops within the screened interval, the plot of h/h_0 vs. t will often have an initial slope and a shallower slope at later time. In this case, the fit should be obtained for the second straight line portion (Bouwer, 1989).

An example of a Bouwer-Rice analysis graph has been included in the following figure:



An example of a Bouwer & Rice slug test is available in the project: AquiferTest\Examples\SlugTest1.HYT.

The Bouwer-Rice Solution assumes the following:

- Unconfined or leaky-confined aquifer (with vertical drainage from above) of “apparently” infinite extent
- Homogeneous, isotropic aquifer of uniform thickness
- Water table is horizontal prior to the test
- Instantaneous change in head at start of test
- Inertia of water column and non-linear well losses are negligible

- Fully or partially penetrating well
- The well storage is not negligible
- The flow to the well is in a steady state
- There is no flow above the water table

Data requirements for the Bouwer-Rice Solution are:

- Drawdown / recovery vs. time data at a test well
- Observations beginning from time zero onward (the value recorded at t=0 is used as the initial displacement value, H_0, by **AquiferTest** and thus it must be a non-zero value)

NOTE: It is important to emphasize that when the Bouwer-Rice method is applied to data from a test in a well screened across the water table, the analyst (user) is adopting a simplified representation of the flow system, i.e., both the position of the water table and the effective screen length, are not changing significantly during the course of the test (Butler, 1998).

For the Bouwer-Rice slug test method, you **must** enter all values for the piezometer geometry.

The effective piezometer radius (**r**) should be entered as the inside radius of the piezometer/well casing if the water level in the piezometer is always above the screen, **or** as calculated by $\mathbf{r_{eff}=[r^2(1-n) + nR^2]^{1/2}}$, where n = porosity, if the water level falls within the screened interval during the slug test (where r = the inside radius of the well, R = the outside radius of the filter material or developed zone, and n = porosity). To use the effective radius, check the box in the **Use r(w)** column in the wells grid (scroll to the very right) of **Slug test** tab.

The radius of the developed zone (**R**) should be entered as the radius of the borehole, including the gravel/sand pack.

The Length of the screened interval (**L**), should be entered as the length of screen within the saturated zone under static conditions.

The height of the stagnant water column (**b**), should be entered as the length from the bottom of the well screen to the top of the aquifer.

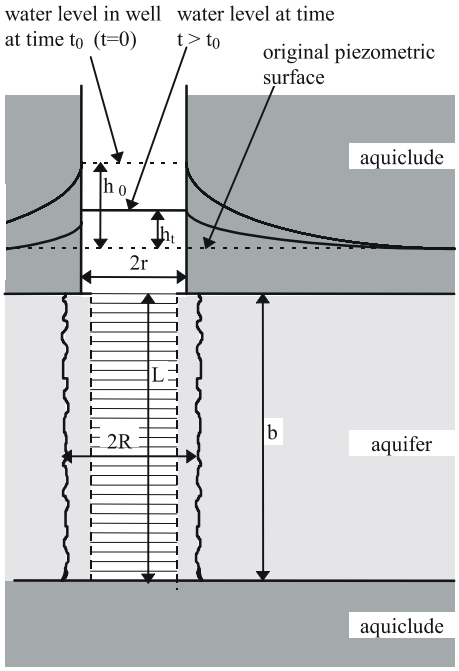
The saturated thickness of the aquifer (**D**), should be entered as the saturated thickness under static conditions.

4.9.2 Hvorslev Slug Test

The Hvorslev (1951) slug test is designed to estimate the hydraulic conductivity of an aquifer. The rate of inflow or outflow, q, at the piezometer tip at any time t is proportional to K of the soil and the unrecoverable head difference:

$$q(t) = \pi r^2 \frac{dh}{dt} = FK(H - h)$$

The following figure illustrates the mechanics of a slug test:



Hvorslev defined the *time lag*, T_L (the time required for the initial pressure change induced by the injection/extraction to dissipate, assuming a constant flow rate) as:

$$T_L = \frac{\pi r^2}{FK}$$

where:

r is the effective radius of the piezometer

F is a shape factor that depends on the dimensions of the piezometer intake (see Hvorslev (1951) for an explanation of shape factors)

K is the bulk hydraulic conductivity within the radius of influence.

Substituting the time lag into the initial equation results in the following solution:

$$K = \frac{\pi r^2 \left(\ln \frac{h_t}{h_0} \right)}{F T_L}$$

where:

h_t is the displacement as a function of time

h_0 is initial displacement.

The field data are plotted with log h_t / h_o on the Y axis and time on the X axis. The value of T_L is taken as the time which corresponds to $h_t/h_o = 0.37$, and *K* is determined from the equation above. Hvorslev evaluated *F* for the most common piezometers, where the length of the intake is greater than eight times the screen radius, and produced the following general solution for *K*:

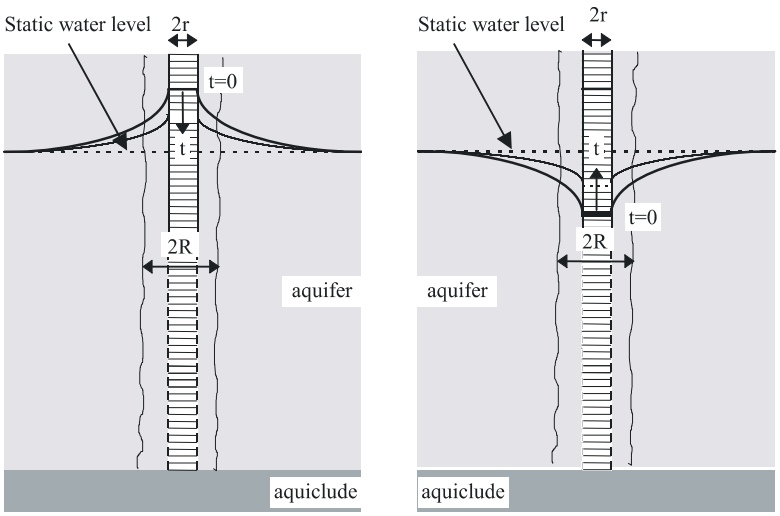
$$K = \frac{r^2 \ln(L / R)}{2 L T_L}$$

where:

L is the screen length
R is the radius of the well including the gravel pack
T_L is the time lag when $h_t/h_0 = 0.37$

The effective piezometer radius, *r*, should be specified as the radius of the piezometer (check the **Use r(w)** in the Wells grid).

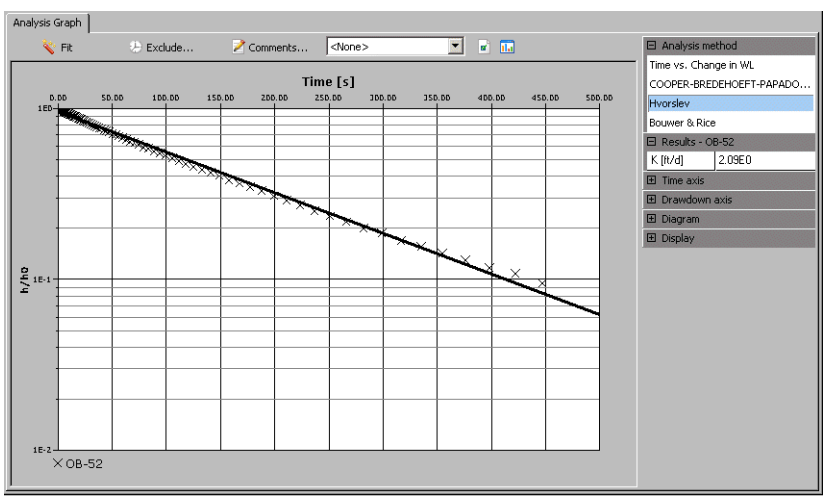
Slug Test **Bail Test**



In cases where the water level drops within the screened interval, the plot of h_t/h_0 vs. t will often have an initial slope and a smaller slope at later time (known in the literature as the ‘double straight line effect’). In this case, you should manually fit the line to the second straight-line portion of the data (Bouwer, 1989). It is not necessary for the line to go through (1,0).

An example of a Hvorslev analysis graph has been included in the following figure

:



An example of a Hvorslev slug test is available in the project: AquiferTestAquiferTest\Examples\SlugTest2.HYT.

The Hvorslev Solution assumes the following:

- Unconfined or non-leaky confined aquifer of “apparently” infinite extent

- Homogeneous, isotropic aquifer of uniform thickness
- Water table is horizontal prior to the test
- Instantaneous injection/withdrawal of a volume of water results in an instantaneous change in water level
- Inertia of water column and non-linear well losses are negligible
- Fully penetrating well
- The well is considered to be of an infinitesimal width
- Flow is horizontal toward or away from the well

Data requirements for the Hvorslev Solution are:

- Drawdown / recovery vs. time data at a test well
- Observations beginning from time zero onward (the observation at t=0 is taken as the initial displacement value, H_0, and thus it must be a non-zero value)

NOTE: Hvorslev has presented numerous formulae for varying well and aquifer conditions. **AquiferTest** uses a formula method that can be applied to unconfined in addition to confined conditions. This method could be applied to unconfined conditions for most piezometer designs, where the length is typically quite a bit greater than the radius of the well screen. In this case, the user must assume that there is a minimal change in the saturated aquifer thickness during the test. Finally, it is also assumed that the flow required for pressure equalization does not cause any perceptible drawdown of the groundwater level. For other conditions and more details, please refer to the original Hvorslev paper.

For the Hvorslev analysis method, you **must** enter all values for the piezometer geometry.

The effective piezometer radius (**r**) should be entered as the inside radius of the piezometer / well casing if the water level in the piezometer is always above the screen, **or** as calculated by $\mathbf{r_{eff}=[r^2(1-n) + nR^2]^{1/2}}$ if the water level falls within the screened interval during the slug test (where r = the inside radius of the well, R = the outside radius of the filter material or developed zone, and n = porosity). To use effective radius, check the box in the **Use r(w)** column of the wells grid (scroll to the very right).

The radius of the developed zone (**R**) should be entered as the radius of the borehole, including the gravel/sand pack. The Length of the screened interval (**L**), should be entered as the length of screen within the saturated zone under static conditions.

4.9.3 Cooper-Bredehoeft-Papadopulos Slug Test

The Cooper-Bredehoeft-Papadopulos (1967) slug test applies to the instantaneous injection or withdrawal of a volume of water from a large diameter well cased in a confined aquifer. If water is injected into the well, then the initial head is above the equilibrium level and the solution method predicts the buildup. On the other hand if water is withdrawn from the well casing, then the initial head is below the equilibrium

level and the method calculates the drawdown. The drawdown or buildup *s* is given by the following equation:

$$s = \frac{2H_0}{\pi}\int_0^{\infty} \exp\left(-\frac{\beta u^2}{\alpha}\right)\left(J_0\left(\frac{ur}{r_c}\right)[uY_0(u) - 2\alpha Y_1(u)] - Y_0\left(\frac{ur}{r_c}\right)[uJ_0(u) - 2\alpha J_1(u)]\right)\left(\frac{1}{\Delta(u)}\right)du$$

where

$$\Delta(u) = [uJ_0(u) - 2\alpha J_1(u)]^2 + [uY_0(u) - 2\alpha Y_1(u)]^2$$

$$\alpha = (r_{w^s}^2 S)/r_{c^c}^2$$

$$\beta = (Tt)/r_c^2$$

and

H_0 = initial change in head in the well casing due to the injection or withdrawal

r = radial distance from the injection well to a point on the radial cone of depression

r_c = effective radius of the well casing

r_w = effective radius of the well open interval

T = Transmissivity of the aquifer

S = Storativity of the aquifer

t = time since the injection or withdrawal

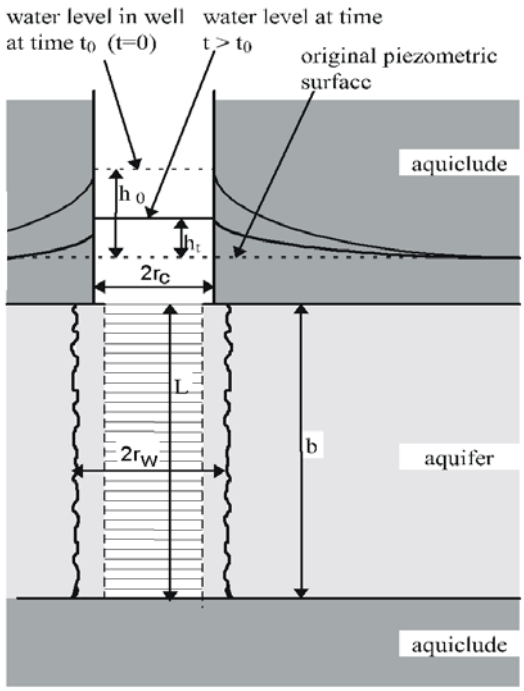
J_0 = Zero Order Bessel function of the first kind

J_1 = First Order Bessel function of the first kind

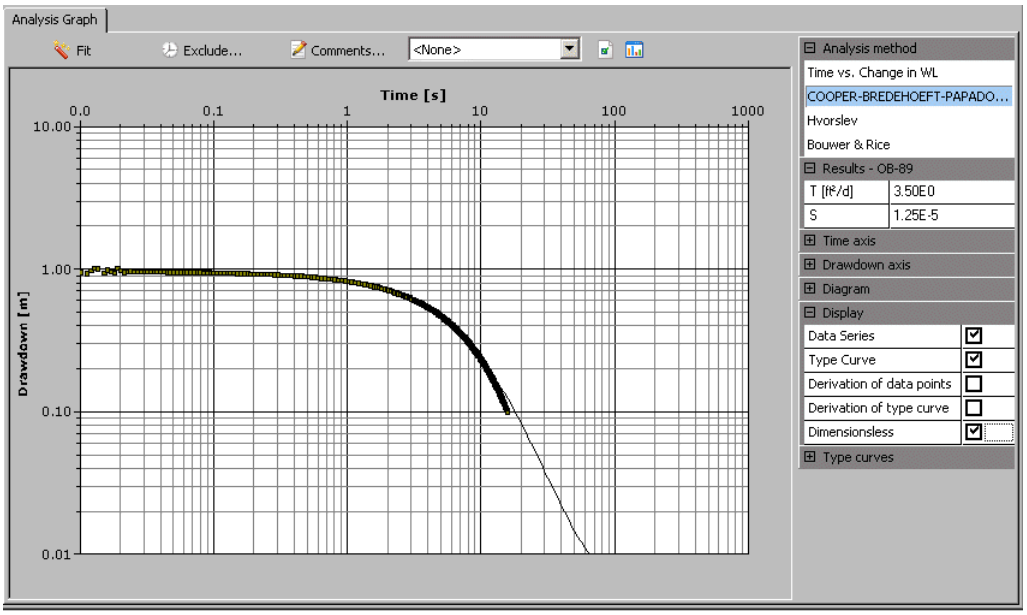
Y_0 = Zero Order Bessel function of the second kind

Y_1 = First Order Bessel function of the second kind

The following diagram illustrates the mechanics for the Cooper-Bredehoeft-Papadopulos Solution:



An example of a Cooper-Bredehoeft-Papadopulos analysis graph has been included in the following figure:



An example of a Cooper-Bredehoeft-Papadopulos slug test is available in the project: AquiferTest\Examples\SlugTest1.HYT.

The Cooper-Bredehoeft-Papadopulos method assumes the following:

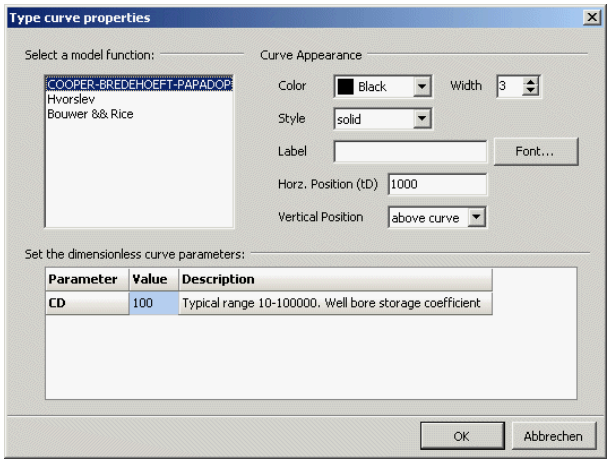
- confined aquifer
- the aquifer is isotropic, homogenous, compressible and elastic
- the layers are horizontal and extend infinitely in the radial direction
- the initial piezometric surface (before injection) is horizontal and extends infinitely in the radial direction
- Darcy's law is valid for the flow domain
- the well is screened over the entire saturated thickness of the aquifer (is fully penetrating)
- the volume of water is injected or withdrawn instantaneously at time t = 0

The data requirements for the Cooper-Bredehoeft-Papadopulos Solution are:

- Time vs. depth to water level at a large diameter test well
- well geometry

Dimensionless Parameters

Additional type curves for this method may be added by changing the CD value, in the Type Curve properties dialog, as shown below.


Type curve properties
Select a model function:
COOPER-BREDEHOEFT-PAPADOP
Hvorslev
Bouwer && Rice
Curve Appearance
Color
Black
Width
3
Style
solid
Label
Font...
Horz. Position (tD)
1000
Vertical Position
above curve
Set the dimensionless curve parameters:
Parameter
Value
Description
CD
100
Typical range 10-100000. Well bore storage coefficient
OK
Abbrechen

4.10 References

Birsoy V.K. and W.K Sumpzers, 1980. Determination of aquifer parameters from step tests and intermittent pumping data. Ground Water, vol. 18, pp. 137-146.

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5

Data Pre-Processing

Surrounding water level trends and barometric affects may have a significant impact on the water levels recorded during your pumping test. **AquiferTest** now includes the tools to analyze these affects to determine if they played a role in your pumping test. Using the data pre-processor utilities, you can correct your water level measurements for baseline trends (trend effects) and barometric pressure changes. This corrected drawdown data should then be used for the calculation of the aquifer parameters.

NOTE: Data Pre-Processing tools are available in AquiferTest Pro only.

According to the U.S. EPA-SOP for Pumping Tests (Osborne, 1993), data pre-processing is a critical step in any pumping test analysis:

"Collecting data on pre-test water levels is essential if the analysis of the test data is to be completely successful. The baseline data provides a basis for correcting the test data to account for on-going regional water level changes. Although the wells on-site are the main target for baseline measurements, it is important to measure key wells adjacent to the site and to account for off-site pumping which may affect the test results." (Osborne, 1993)

During the baseline trend observation period, it is desirable to monitor and record the barometric pressure to a sensitivity of +/- 0.01 inches of mercury. The monitoring should continue throughout the test and for at least one day to a week after the completion of the recovery measurement period. This data, when combined with the water level trends measured during the baseline period, can be used to correct for the effects of barometric changes that may occur during the test." (Osborne, 1993)

For more details, please see:

EPA Groundwater Issue: Suggested Operating Procedures for Aquifer Pumping Tests

Paul S. Osborne, EPA/540/S-93/503, February 1993

5.1 Baseline Trend Analysis and Correction

Historic and baseline water level trends can impact the drawdown data you record during your pumping test. Surrounding pumping activities, or even surface disturbances

such as trains, can effect the water level during the pumping test. It is important to identify all major disturbances (especially cyclic activities) which may impact the test data. Enough measurements have to be made to fully characterize the pre-pumping trends of these activities (Osborne, 1993). Therefore, the user must record water levels near or at the well, either before or after the test. (For example, daily water level measurements taken 1 week prior to the test, up to the day of the test, is a general recommendation from the EPA.) Using the measured trend data, **AquiferTest** performs a line fit to calculate a trend coefficient. The program will also run a “t-test”, to see if the trend is significant. If significant, the data is then corrected based on this trend.

As an example, a trend analysis shows a trend of water levels rising 2cm/hr due to surrounding activities. During the pumping test, for a water level recorded 3 hours after the test begins, you need to add 6 cm to the water level measurements in order to conduct a representative analysis of the aquifer.

If the data trend is already known (i.e. water level fluctuations due to tidal or ebb-flows), then the trend can be defined using a simple linear time-dependent correction. For more details, see “Customized Water Level Trends” on page 218.

A trend analysis generally involves the following steps:

1. Collect baseline trend data (time vs. water level) prior to, and after, the test; measurements should be recorded at a location that will not be influenced by the pumping test activities.

2.**AquiferTest** calculates a baseline trend, and trend coefficient. **AquiferTest** calculates the simple linear regression of the measured values and runs a t-test to determine if the trend is significant.

3. Apply the trend coefficient to the data collected during the pumping test (time vs. water level), resulting in “corrected drawdown” measurements.

4. Use the corrected drawdown values for the calculation of the aquifer parameters.

5.1.1 Theory

The general formula for trend computation is a polynomial and a function of the time t:

$$XT(t) = \sum_{k=0}^{m} b_k t^k$$

where

k= 0, 1, 2, ...m

Only the linear part of the trend is considered for hydrogeological observations (trend of 1st order):

$$XT(t) = b_0 + b_1 t$$

To calculate b_0 and b_1, the standard regression analysis is used. To check the quality of the trend, compare the linear correlation coefficient with tabular values for the t-test, available in most statistical texts. A linear coefficient value is calculated that can be used to calculate corrected drawdown at the observation wells. **AquiferTest** calculates the change in water level based on the trend.

t-Test (Student-test)

To check the trend for statistical significance, the Pearson correlation coefficient r, is calculated as below:

$$r = \frac{n\left(\sum XY\right) - \left(\sum X\right)\left(\sum Y\right)}{\sqrt{\left[n\left(\sum X^2\right) - \left(\sum X\right)^2\right]\left[n\left(\sum Y^2\right) - \left(\sum Y\right)^2\right]}}$$

The calculated value of r is compared with the “critical value”. The critical values are available in tabular form, in most statistical reference books.

To calculate the critical value, first obtain the value of quantile of the test, t α,DF

There are two required parameters:

α: confidence interval

DF: degrees of freedom, which is n-2 (n = number of data points)

The formula to calculate, $t_{\alpha,DF}$ is complex, and is not illustrated in this manual.

The confidence interval can be defined in **AquiferTest** in the main menu under **Tools / Options**, and under the **Constants** tab. The default value is 95%.

To obtain the critical value $r_{\alpha,DF}$, the formula from Sachs (1974) is used:

$$r_{\alpha,DF} = \frac{t_{\alpha,DF}}{\sqrt{t_{\alpha,DF}^2 + n - 2}}$$

If the absolute value of the Pearson coefficient (r) is GREATER than the “critical value” ($r_{\alpha,DF}$) then the trend is SIGNIFICANT.

If the absolute value of the Pearson coefficient (r) is LESS than the “critical value” ($r_{\alpha,DF}$) then the trend is NOT SIGNIFICANT.

Reference: Langguth & Voigt (1980), 413 ff.

Example

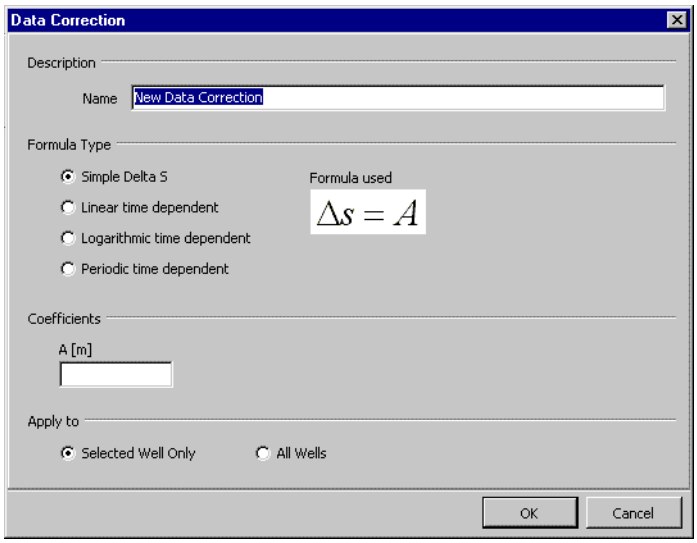
An example demonstrating a data trend analysis is available in Chapter: 7, Exercise 5: Adding Data Trend Correction.

5.2 Customized Water Level Trends

AquiferTest provides the option to create a user-defined correction factor, and apply this to the observed drawdown data.

In confined and leaky aquifers, rhythmic fluctuations of the hydraulic head may be due to the influence of tides or river-level fluctuations, or to rhythmic variations in the atmospheric pressure. In unconfined aquifers whose water tables are close to the surface, diurnal fluctuations of the water table can be significant because of the great difference between day and night evapotranspiration. The water table drops during the day because of the consumptive use by the vegetation, and recovers during the night when the plant stomata are closed (Kruseman and de Ridder, 1991).

To access the User Defined Data Corrections, go to the **Water Levels** tab, click on the **Add Data Correction** button and the following dialog will appear:



In the **Data Correction** dialog, enter a name for the correction, then select a formula type. There are four formula types to choose from:

Simple Delta S (drawdown)

$$\Delta s = A$$

Linear Time Dependent

$$\Delta s = A \cdot t$$

Logarithmic Time Dependent

$$\Delta s = A \cdot \log_{10}\left(B + C \cdot t\right)$$

Periodic Time Dependent

$$\Delta s = A \cdot \left(\sin\left[B + C \cdot t\right]\right)^{D}$$

Depending upon selected type, there will be input fields for the different coefficients (A, B, C, and D).

Determining the values of the coefficients is a complex process, which depends on the type of data correction and the cause of the displacement.

In short for the four different types:

- addition/subtraction: this is simple +- operation, could be used to correct wrong offsets of logger measurements
- linear time function: general trend correction, i.e. if the change of water level in the aquifer can be approximated by a linear function for the time of the pumping test. An Example would be seasonal drainage.
- log function of time: An Example would be drainage of an aquifer after precipitation.
- periodic function, could be tidal effects

Note: It is not possible to apply a data correction only to a certain period of time, it always applies to all data. It is only possible to limit to a particular well.

For tidal corrections, the coefficients are defined as follows:

A: amplitude, half amount of the tidal change during one period (high - low tide)

B: phase displacement, calculated as follows; For example, 2 hours after ebb: = (PI/ 2) + [(2h/ 6.2h) * PI]. Please note that B is dimensionless, so it must be given in radian

C: period = (PI/12 h 25 min)

D: = 1

The range of application indicates whether the correction applies only to the current well data set, or to all wells. For example, a local trend usually affects all wells, while a periodic correction of the Tidal influences depends on the distance to the sea, and therefore must be unique for each observation well.

When defining the coefficients, be aware of the sign (positive or negative). The result of the calculation is added to the drawdown values; i.e. if the value is positive, the drawdown increases; for negative values, the drawdown decreases. For example, if you have a local trend where the water table decreases 1cm/d, the value must then be defined as negative, so that the appropriate amount is subtracted from the observed drawdown. Alternatively, if the trend shows the water table elevation rising 1cm/day, the value must then be defined as positive, so that the appropriate amount is added to the observed drawdown data.

Upon clicking OK, the data correction will be applied to the measured drawdown data, and an additional column will appear in the data table. This column will contain the corrected drawdown using this data correction; the corrected drawdown will be used in the analysis to calculate the aquifer parameters.

5.3 Barometric Trend Analysis and Correction

During the pumping test, changes in the barometric pressure can have an affect on the recorded drawdown data, and should be considered during the data analysis. **AquiferTest** includes the tools to correct drawdown data for barometric effects, using data pre-processor tools. Barometric pre-processing generally involves the following steps:

1. Collecting data (barometric pressure vs. water level) prior to, or after, the test;

2. Use this data to calculate the barometric efficiency (BE) of the aquifer.

3. During the pumping test, collect time vs. water level data AND time vs. barometric pressure data.

4. Using the BE value, determine the equivalent water level measurement at the observed time. If the pressure is not recorded at the same time as the water levels, linear interpolation may be used to find and correct the next available water level measurement.

5. Apply the correction to the observed drawdown data.

6. Use the corrected water levels for determining the aquifer parameters.

Theory

In wells or piezometers penetrating confined and leaky aquifers, the water levels are continuously changing as the atmospheric pressure changes. When the atmospheric pressure decreases, the water levels rise in compensation. When the atmospheric pressure increases, the water levels decrease in compensation. By comparing the atmospheric changes, expressed in terms of a column of water, with the actual changes in water levels observed during the pre-test period, it is possible to calculate the barometric efficiency of the aquifer. (Kruseman and de Ridder, 1991)

The barometric efficiency (BE) is a parameter of the aquifer, and specifies how it reacts to changes in atmospheric pressure. The BE value usually ranges between 0.2 and 0.75. The BE is defined as the ratio of change in water level in a well (Δ h) to the corresponding change in atmospheric pressure (Δ p)

$$BE = \frac{\Delta h \cdot \gamma}{\Delta p}$$

with

Δ h = change in water level [m]

Δ p = change in pressure [Pa = N/m²]

γ = specific weight of water [N/m³] (this value can be defined in the **Tools / Options**, **Constants** tab)

The specific weight (γ) is defined as

$\gamma = \rho \cdot g$

ρ= density of water (Kg/m^3)

g= acceleration of gravity (m/s^2)

The acceleration of gravity (g) depends on geographic latitude. For most places on Earth, the value is 9.82 m/s². However, if you are close to the equator the value decreases to 9.78 m/s², whereas close to the poles (North or South) it is about 9.83 m/s².

The density of water (ρ) is a function of the temperature. At 10°C, the value is 999.7 kg/m³. However, for heated thermal water or water with solute minerals a correction of this value may be necessary.

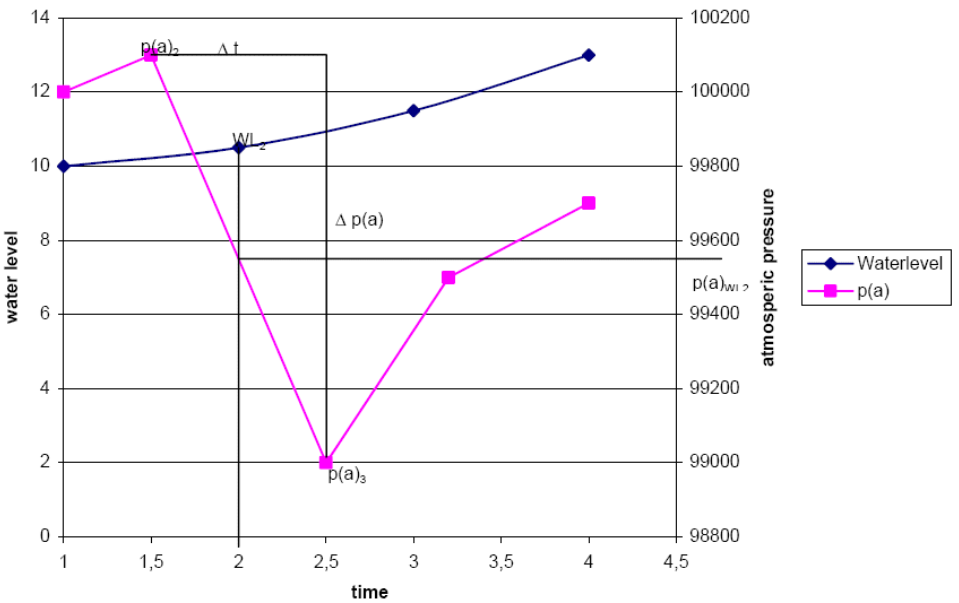
The default value for (γ) used in **AquiferTest** is 9807.057 N/m³.

To calculate the change of water level in an aquifer caused by the atmospheric pressure change alone, rearrange the formula for the BE, to get:

$$\Delta h = \frac{BE\Delta p}{\gamma}$$

The Barometric Efficiency (BE) may be entered directly into **AquiferTest** (in the Pumping Test tab), or may be calculated. To calculate the BE value, the user must provide pressure vs. water level data recorded from a well near the test site, before or after the test.

Once the BE is known, the measured drawdown can be corrected. To do so, the user must provide time vs. pressure data, recorded DURING the pumping test. It is possible that the atmospheric pressure measurements are not recorded at the same point in time as the drawdown measurements. In this case, **AquiferTest** uses linear interpolation between the next available pressure value, to modify the original data. An example is illustrated below:



In the figure above you can see how **AquiferTest** will interpolate the atmospheric pressure p(a) for the time of water level measurement WL2 at t=2 where no value for p(a) is available.

AquiferTest will use the values of $p(a)_2$ and $p(a)_3$ for linear interpolation and to calculate a straight line function of the form y = mx + b.

$$m = \frac{\Delta p(a)}{\Delta t} = \frac{p(a)_3 - p(a)_2}{t_{p(a)3} - t_{p(a)2}} = \frac{99000 - 100100}{2.5 - 1.5} = \frac{-1100}{1} = -1100$$

$$b = y - mx = 100100 - (-1100 \cdot 1.5) = 100100 + 1650 = 101750$$

Once the coefficients m and b are calculated the value of t=2 will be inserted into the equation, y = mx + b, and the result is the value of p(a)WL2 used for the calculation of Δh_p.

$$p(a)_{t=2} = -1100 \cdot 2 + 101750 = 99550$$

From the changes in pressure observed during the test, and the known relationship between Δp and Δh, the water level changes as a result of changes in pressure alone (Δp) can be calculated for the test period for each well. Subsequently, the actual drawdown during the test can be corrected for the water level changes due to atmospheric pressure:

For falling atmospheric pressures,

$s_{corr} = s + \Delta h_p$

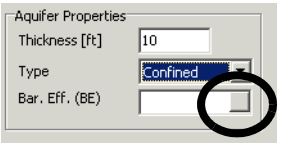
For rising atmospheric pressures,

$s_{corr} = s - \Delta h_p$

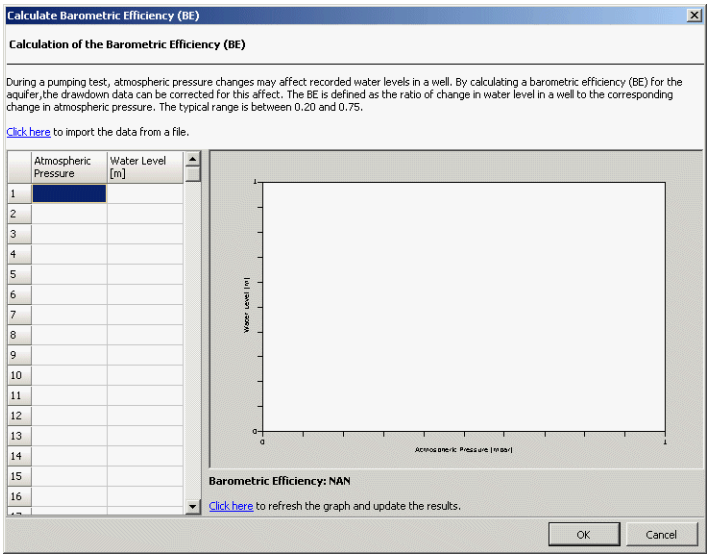
(Kruseman and de Ridder, 1991)

Calculating BE from Observed Data

The BE value can be defined in the **Pumping Test** tab, or it may be calculated based on observed data. To calculate the BE value, locate the **Bar.Eff. (BE)** field in the **Aquifer Properties** frame of the **Pumping Test** tab, and press the button beside the BE field.



A blank window for barometric data entry will appear.

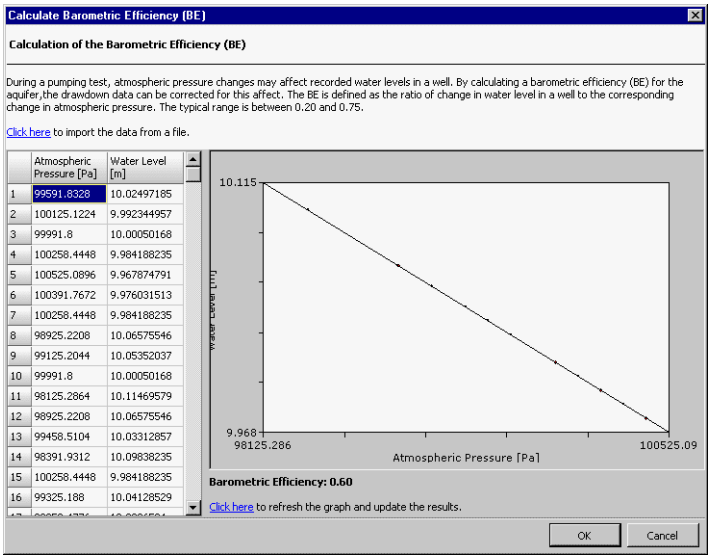

Calculate Barometric Efficiency (BE)
Calculation of the Barometric Efficiency (BE)
During a pumping test, atmospheric pressure changes may affect recorded water levels in a well. By calculating a barometric efficiency (BE) for the aquifer,the drawdown data can be corrected for this affect. The BE is defined as the ratio of change in water level in a well to the corresponding change in atmospheric pressure. The typical range is between 0.20 and 0.75.
Click here to import the data from a file.
Atmospheric Pressure
Water Level [m]
Barometric Efficiency: NAN
Click here to refresh the graph and update the results.
OK
Cancel

In this window, enter Pressure vs. Water Level data. This data must be recorded before or after the test, at a location near the test well. The data values can be entered in the grid on the left hand side. Or to import data, click on the appropriate link above the table. Data may be imported in .TXT or .XLS formats.

When importing data, observe the following requirements:

- the source file must be in the same units as the test
- data file must be .TXT or .XLS, with two columns of data (pressure and water level)

Once the data is entered, the dialog will look similar to the following:

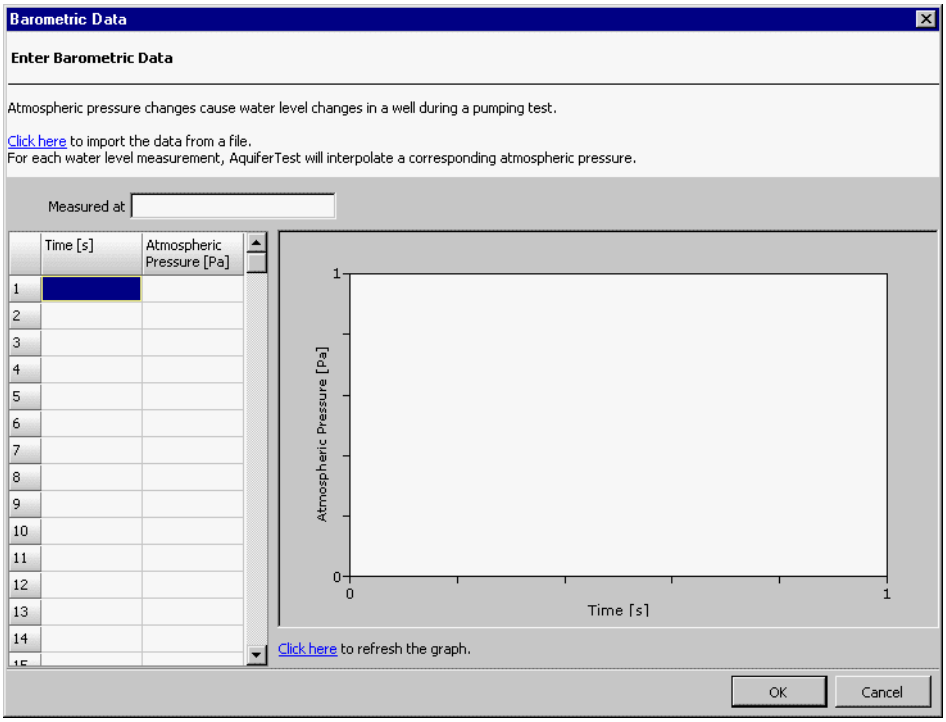

Calculate Barometric Efficiency (BE)
Calculation of the Barometric Efficiency (BE)
During a pumping test, atmospheric pressure changes may affect recorded water levels in a well. By calculating a barometric efficiency (BE) for the aquifer,the drawdown data can be corrected for this affect. The BE is defined as the ratio of change in water level in a well to the corresponding change in atmospheric pressure. The typical range is between 0.20 and 0.75.
Click here to import the data from a file.
Atmospheric Pressure [Pa]
Water Level [m]
1 99591.8328 10.02497185
2 100125.1224 9.992344957
3 99991.8 10.00050168
4 100258.4448 9.984188235
5 100525.0896 9.967874791
6 100391.7672 9.976031513
7 100258.4448 9.984188235
8 98925.2208 10.06575546
9 99125.2044 10.05352037
10 99991.8 10.00050168
11 98125.2864 10.11469579
12 98925.2208 10.06575546
13 99458.5104 10.03312857
14 98391.9312 10.09838235
15 100258.4448 9.984188235
16 99325.188 10.04128529
10.115
9.968
98125.286
100525.09
Atmospheric Pressure [Pa]
Barometric Efficiency: 0.60
Click here to refresh the graph and update the results.
OK
Cancel

The dialog displays a graph with the data and fits a line – and calculates the BE value.

Click **[OK]** to accept the barometric efficiency value. This value will now appear in the BE field in the Pumping Test tab.

Correct Observed Drawdown Data for Barometric Effects

Once the BE value has been determined, it can be used for correcting the observed drawdown data. To do so, load the **Water Levels** tab, and ensure there is time drawdown data for an existing well. Then, select "**Add Barometric Correction**" and the following window will appear:

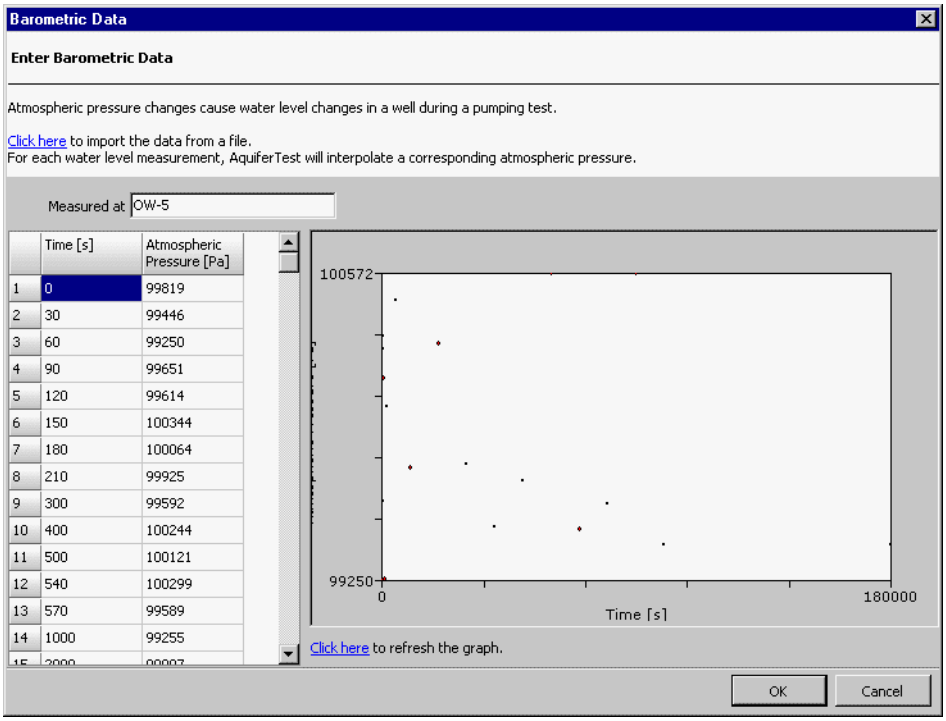

Barometric Data
Enter Barometric Data
Atmospheric pressure changes cause water level changes in a well during a pumping test.
Click here to import the data from a file.
For each water level measurement, AquiferTest will interpolate a corresponding atmospheric pressure.
Measured at
Time [s]
Atmospheric Pressure [Pa]
Atmospheric Pressure [Pa]
Time [s]
Click here to refresh the graph.
OK
Cancel

In this window, enter time vs. pressure data, that was recorded simultaneously as the time drawdown data. As mentioned earlier, if the time measurements were not recorded at exactly the same time intervals, **AquiferTest** will use interpolation to correct the next available water level measurement.

When importing data, observe the following requirements:

- the source file must be in the same units as the test
- data file must be .TXT or .XLS, with two columns of data (time vs. pressure)

The example below shows a sample data set of time - pressure data.



Click **[OK]** to close the dialog, and return to the **Water Levels** window. In the time - water level grid, two new columns will appear beside the drawdown column. The first column contains the correction due to barometric effects; the second column contains the new corrected drawdown value. The following equation is used:

$$s_{corr} = s + \Delta h_p$$

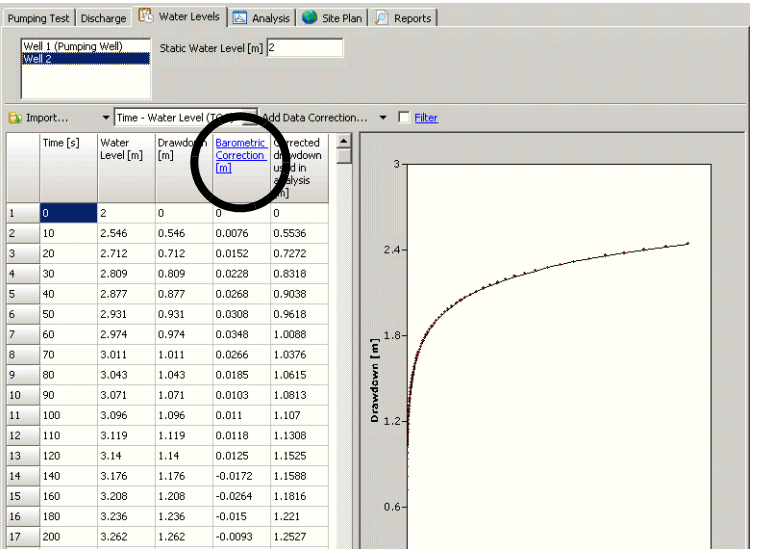
The corrected drawdown measurements can then be used in the analysis, to calculate the aquifer parameters.

Example

An example demonstrating a barometric trend analysis is available in Chapter: 7, Exercise 6: Adding Barometric Correction.

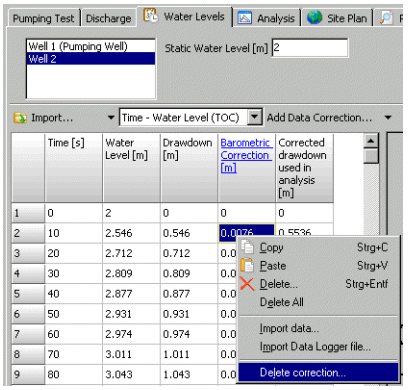
5.4 Modifying Corrections

When a data correction is created, the correction column header appears blue. This header is created as a link, and clicking on it will allow you to access and modify the settings for the correction.



5.5 Deleting Corrections

To delete a data correction (barometric, user-defined, or baseline trend effects), place the mouse in the data correction column, right mouse click, and select "**Delete Data Correction**" from the context menu (as shown below).



This option is available only if the cursor is in the table and in a column with correction data.

6

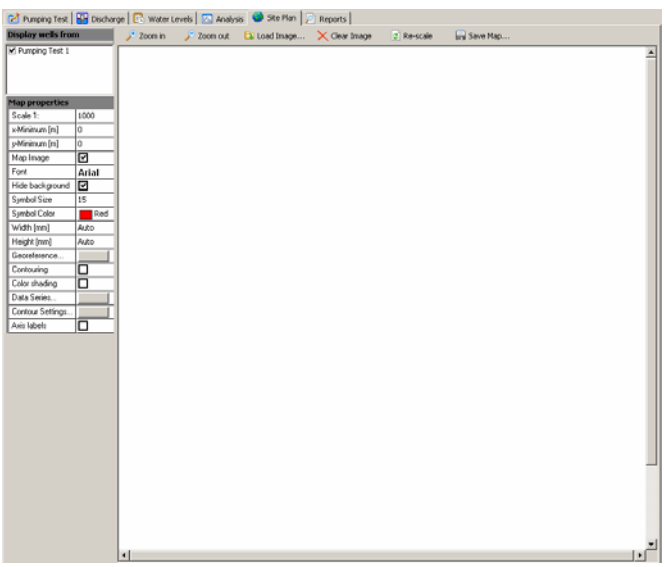
Mapping and Contouring

AquiferTest now includes enhanced mapping features, which allow you to display contouring and color shading of drawdown data, along with site maps, in the Site Map window.

NOTE: Contouring and Color Shading is available in AquiferTest Pro only.

6.1 About the Interface

The mapping and contouring options are available under the **Site Plan** tab, displayed in the image below:



This tab allows you to load a map of the site of the project. You can only load one map per project. For instructions on how to load a map see description of **[Load Image...]** button below.

The **Site Plan** tab is managed using a tool bar located above the map image, and the **Display wells from** and **Map properties** dialog boxes.

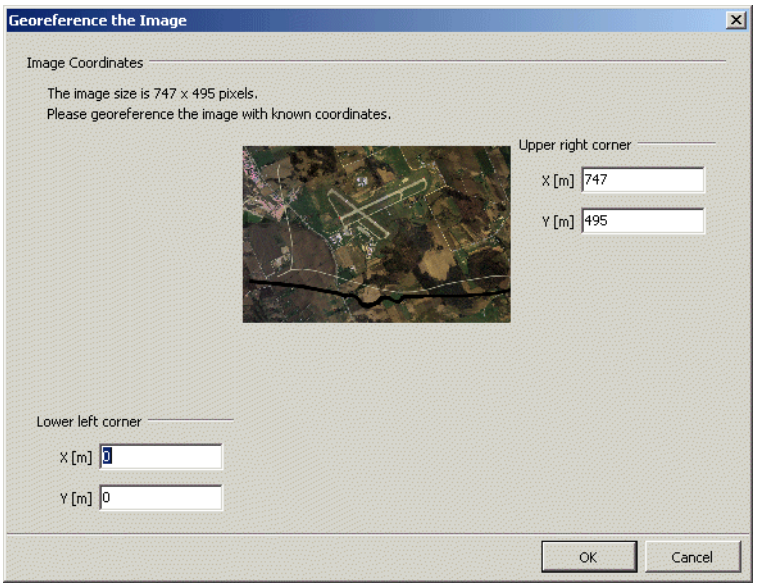
The tool bar consists of the following buttons:

Zoom in - draw a rectangle around the area you wish to magnify.

Zoom out - zoom out to the full extent of the map

Load Image... - opens an Explorer window where you can navigate to the appropriate image file containing the map. Supported image formats are *.bmp, *.wmf, *.emf, *.jpg, and *.dxf.

- Select the image file and click **Open** and the following dialog will load.

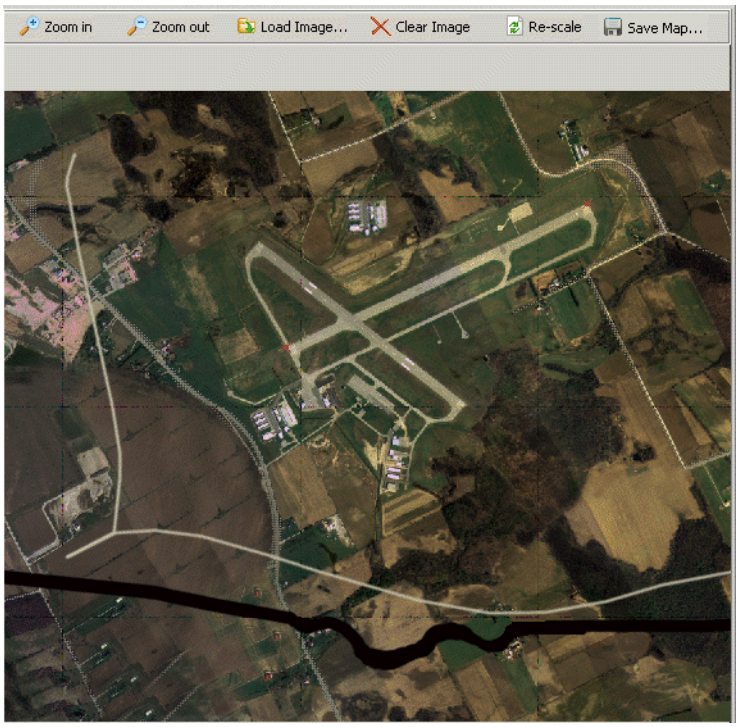


- In this dialog, georeference the image by entering the coordinates for the map's lower left and upper right corners.

NOTE: By default, the number of pixels are converted to meters to keep the map proportions.

- Click **[OK]**

After georeferencing the image will appear similar to the image below:



After the map is loaded, you may need to re-scale or zoom in/out to achieve the desired view.

Clear Image - deletes the image from the map field

Re-scale - allows you to re-scale the map

The **Re-scale** determines the range of real coordinates for the wells in the pumping test:

Range x = Max x - Min x

Range y = Max y - Min y

The Re-Scale also determines the origin of the wells in real coordinates:

Origin x = Min x

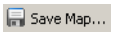
Origin y = Min y

Finally, the Re-Scale calculates a scale both for x and y, to ensure that all wells are displayed on the map.

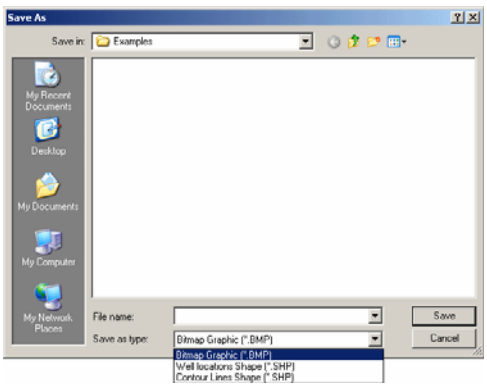
Scale x = Map width (mm) / Range x

Scale y = Map width (mm) / Range y

AquiferTest will use the scale that is the smaller from both calculations. The value is then rounded down, to a typical scale number, which is divisible by 10. (for example, 1:875 would go to 1:1000). AquiferTest does not use the full map width/height for the calculation, in order to have a buffer distance on the map, so that wells which lie on the map edge are not truncated. (This may result in a negative value for X or Y min). The rescale does not change width or height of the map, zoom factor or view port.



Save Map... - allows you to save the sitemap in bitmap (*.BMP) format. This option also allows you to export drawdown contour lines and project wells to shapefile format (*.SHP). Upon selecting this option, a Windows explorer dialog will open, as shown below.



Navigate to the desired folder location on your hard drive, and specify a file name. From the **Save as type** combo box, select the file type you would like to export, e.g, Bitmap Graphic (*.BMP), Well Locations Shape (*.SHP) or Contour Lines Shape (*.SHP). Finally, click **Save** to export the data.

The **Display wells from** option allows you to select the pumping test with the appropriate wells. Select all the boxes to display all wells in the project.

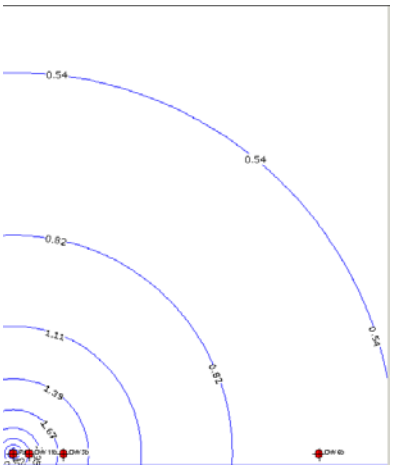
NOTE: If no map is loaded the wells will be displayed on a white background.

In the **Map properties** dialog you can change the following settings:

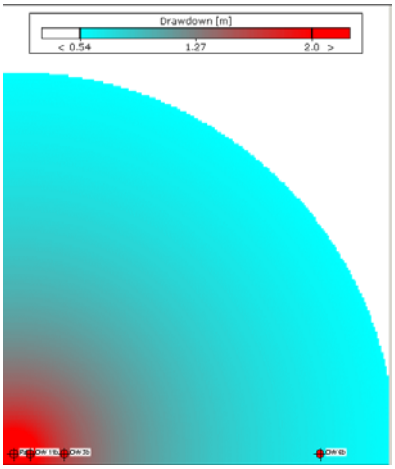
- **Scale 1:** - specify the scale for the map/drawing canvass. This is the ratio between distance on the printed map and the actual dimensions. i.e. 1:1000 means 1 cm in the map is equivalent to 1000 cm (or 10 m).
- **x-Minimum [ ]** - the x-coordinate of the left edge of the map field
- **y-Minimum [ ]** - the y-coordinate of the bottom edge of the map field
- **Map Image** - check-box that allows you to show/hide the map image
- **Font** - modify the font for the well name
- **Delete background** - check-box that allows you to show/hide the background box around the well name
- **Symbol Size** - define the size of the well symbol

- **Symbol Color** - select a color for the well symbol
- **Width** - controls the area map width; modify this value for printing purposes. To restore the default, enter Auto in this field
- **Height** - controls the map height; modify this value for printing purposes. To restore the default, enter Auto in this field
- **Georeference...** - loads the same **Georeference the image** dialog box as during the **Load Image** procedure. Allows you to assign new georeference points for the map image
- **Contouring** - enable or disable contour lines using this check-box
- **Color shading** - enable or disable color contouring using this check-box

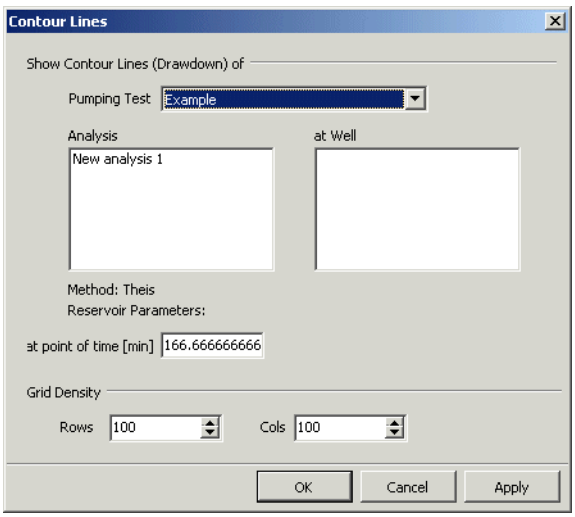
Contour Lines



Color Shaded



- **Data Series...** - provides options to select the pumping test data set for contouring. These options are shown below:

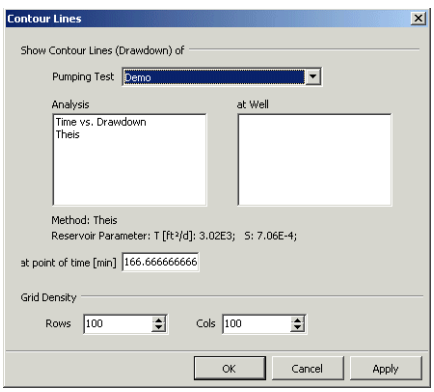


Specify the pumping test, the analysis, the well, and the point in time from which to draw data for contouring, as well as the grid specifications. A larger grid size (> 100X100) will result in greater detail, and smoother contour lines, but may also increase processing time.

- **Contour Settings...** - loads the dialogues that allow you to fine-tune the line and color contouring, as well as edit the legend and labels. For more details, see Chapter 6: Contouring and Color Shading Properties below.
- **Axis Labels** - allows you to display the X and Y axis interval labels on the report view; useful for interpreting maps to scale.

6.2 Data Series

Before you can display contours or a color may, you must select the pumping test, well, and time interval. This is done in the **Data Series** dialog. Load the **Data Series** options from the **Map** properties frame. The dialog is shown below.



- **Pumping test** - select the pumping test for which you wish to generate contours.

NOTE: Contouring is not available for Slug Tests.

- **Analysis** - from the list of the analyses available for the selected pumping test, choose the one for which you wish to generate contours
- **Well** - from the list of wells used in the selected analysis, choose the one for which you wish to generate contours
- **at point of time [ ]** - type in the point in time for which you wish to view the contouring
- **Grid Density** - allows you to set the number of rows and columns for the grid used to generate contours. The higher the number of rows and columns, the finer the grid. A fine grid allows for smoother contours, however it also takes longer to process.

AquiferTest calculates contours based on the pumping rate of the selected pumping test and the Transmissivity and Storativity values calculated in the selected analysis. If

you enter a point in time which is AFTER the test time period, there are two possibilities for the drawdown calculations:

- In case of **constant** pumping rate, the pumping duration is assumed to be infinite.
- In case of **variable** pumping rate, it is assumed that the pumping has stopped after the last pumping period, and the time afterwards is recovery.

Exporting Gridded Drawdown Data

Once the grid has been calculated, you may export the grid values to a text file for interpretation/analysis with other tools. Simply right-mouse click on the **Map** window, and select **Export Grid**. A dialog will appear, prompting for a filename. The file will be saved as a tab-delimited text file, containing three columns: X, Y, Drawdown.

Exporting Drawdown Contours

You can export drawdown contours to shapefile format by clicking on the Save Map button in the toolbar. Specify a filename, and select the **Contours Line Shape *.SHP** option from the **Save As Type** combo box.

Exporting Wells

You can export project wells to shapefile format by clicking on the Save Map button the toolbar. Specify a filename, and select the **Well locations shape *.SHP** option from the **Save As Type** combo box.

Exporting Site Map

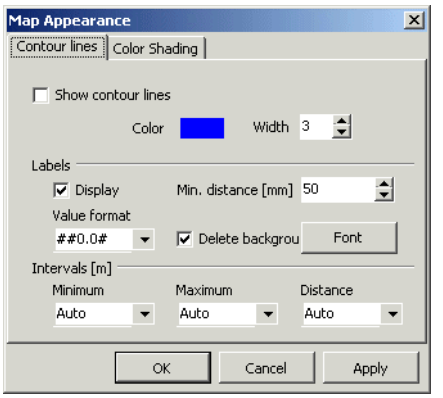
Once the site map is displayed to your liking, you have a few options for exporting:

- Click on the Copy icon on the toolbar, then paste the map image into an image editor
- Click on the Save Map icon. The image can be saved as a .BMP file, then loaded into an image editor for further processing, or converting to alternate formats.

By default, AquiferTest will create an image that is high resolution (1859 X 2094).

6.3 Contouring and Color Shading Properties

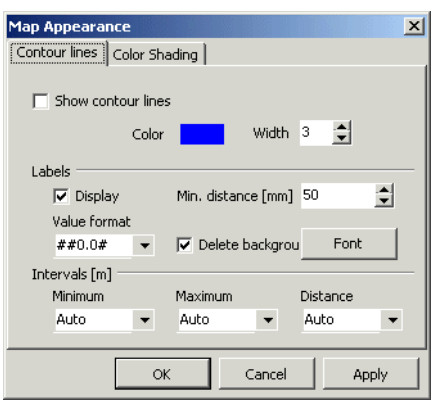
The Contouring and Color Shading map properties may be accessed by clicking **Contour Settings** button from the **Map Properties** frame of the **Site Plan** tab.The **Properties** window for the graph will appear, as shown in the following figure:



The **Map Appearance** window contains two tabs:

- The **Contour lines** settings tab is used to set the appearance properties for the contour lines and labels.
- The **Color Shading** tab is used to set the appearance properties for the color shading contours.

6.3.1 Contour lines tab



The **Show contour lines** check-box is used to enable/disable the line contours. The same function is performed by clicking the **Contouring** check-box in the **Map Properties** frame of the **Site Plan** tab.

In addition, you may specify the line color and width.

Labels frame

Under the **Label** frame, specify the display properties for the contour labels.

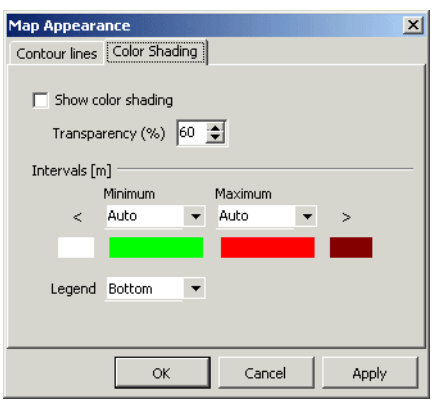
- the **Value Format** controls the number of decimal places for the contour labels
- the **Min. Distance** value controls the space between the contour labels (the smaller the value, the closer and more numerous the labels will be)
- the **Delete Background** check box allows you to show/hide the background box around the label. This feature is helpful if you want to read the labels on top of a map or the color shading.
- **Font** - select the label font, size, style, and color

Intervals frame

Under the **Intervals** frame, specify the range of values for the contour lines:

- **Minimum** - specify the minimum value for the contour line; Auto is the default.
- **Maximum** - specify the maximum value for the contour line; Auto is the default.
- **Distance -** set the value for the interval between the contour lines. The smaller the Distance value, the more numerous and closer the contour lines will be.

6.3.2 Color Shading tab



The **Show Color shading** check-box allows you to show/hide the color shaded map. The same function is performed by clicking the **Color Shading** check box in the **Map Properties** frame of the **Site Plan** tab.

The **Transparency (%)** value is used only when there is a site map image in the background, and you want to display the color shading on top. A higher Transparency value will result in a more transparent color shaded map, allowing you to view the map layer below. (100 % Transparency will make the color shading completely transparent). A lower Transparency value will result in a less transparent color shaded map (i.e.

darker color shading). 0 % Transparency will make the color shading non-transparent, and will hide the underlying site map.

Intervals frame

Specify the range of values to use for the color shading map.

- **<** - allows you to specify a color for values that are below (less than) the **Minimum** value; this is useful if you want to assign a unique color to a threshold/cut-off value.
- **Minimum** - specify the color for the minimum value; the default minimum value is Auto
- **Maximum** - specify the color for the maximum value; the default value is Auto
- **>** - allows you to specify a color for values that are above (greater than) the **Maximum**; this is useful if you want to assign a unique color to a threshold value.

At the bottom of this dialog, you can set the position for the **Legend**.

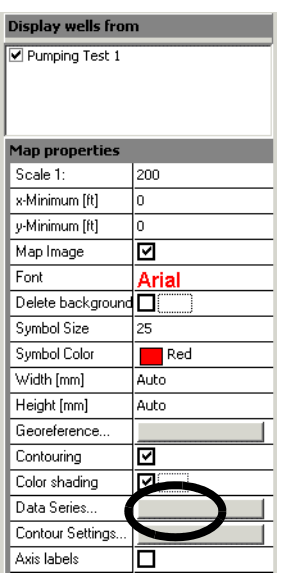
6.4 Example

The following example will illustrate the use of contours in a pumping test.

[1] Start AquiferTest, and open the Confined.HYT project, located in the “Examples” directory (you may also try creating a drawdown map using the Getting Started example from Chapter 2).

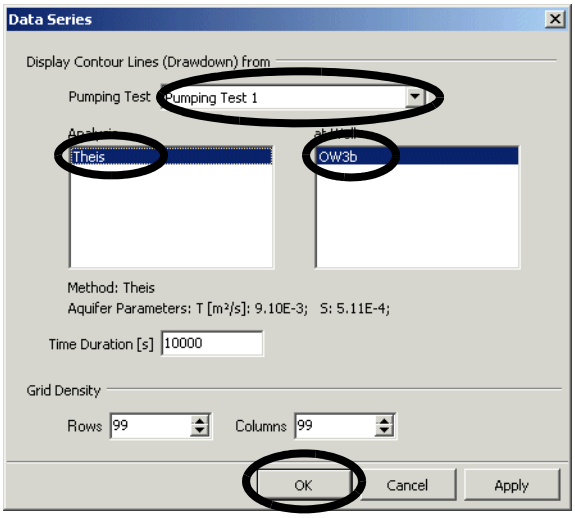
[2] In this example, using a Theis analysis, the calculated parameters are:
T = 9.10 E-3 (m2/s), and
S = 5.11 E-4

[3] Move to the **Site Plan** tab, and click on the **Data Series** button



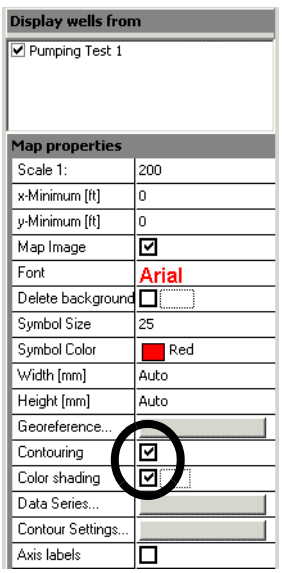
[4] In this dialogue, select the pumping test from the top, the appropriate analysis (**Theis**

in this example), and the well where the data was observed (**OW3b),** and the time duration. Once you select the Well, you will see a preview of the calculated Aquifer Parameters directly below the list box. You may also define the grid size, however the default is fine for this example.

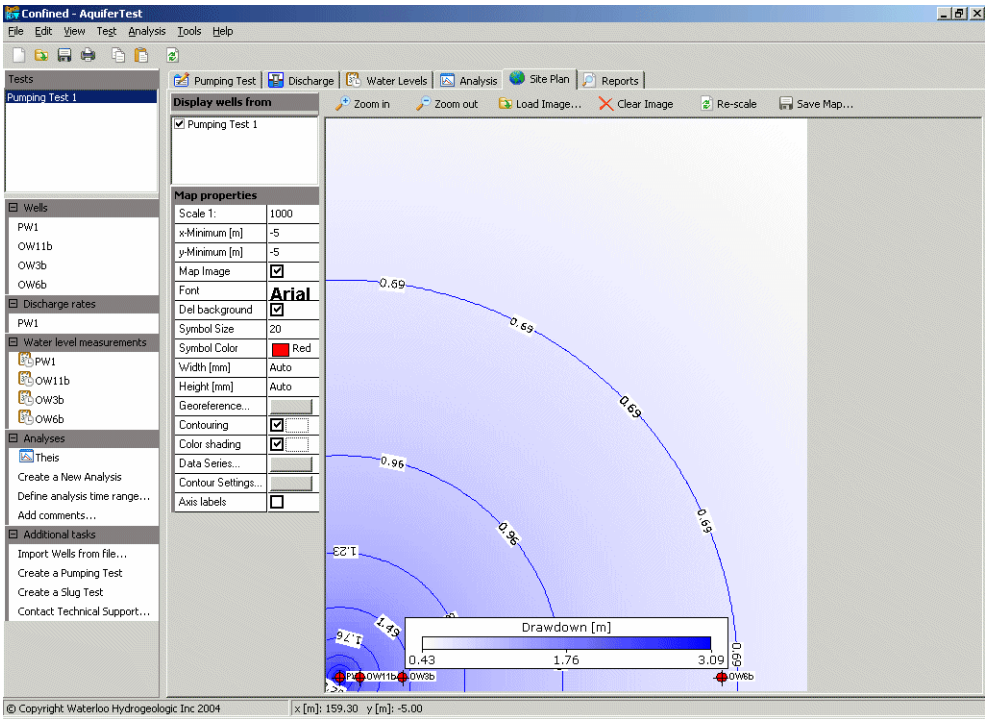


[5] Click **[OK]**

[6] Check the boxes beside **Color shading** and **Contouring**



[7] Click the **Zoom Out** button until you see the following figure:



The line contours are blue-colored by default, and the color shading is mono-chromatic blue.

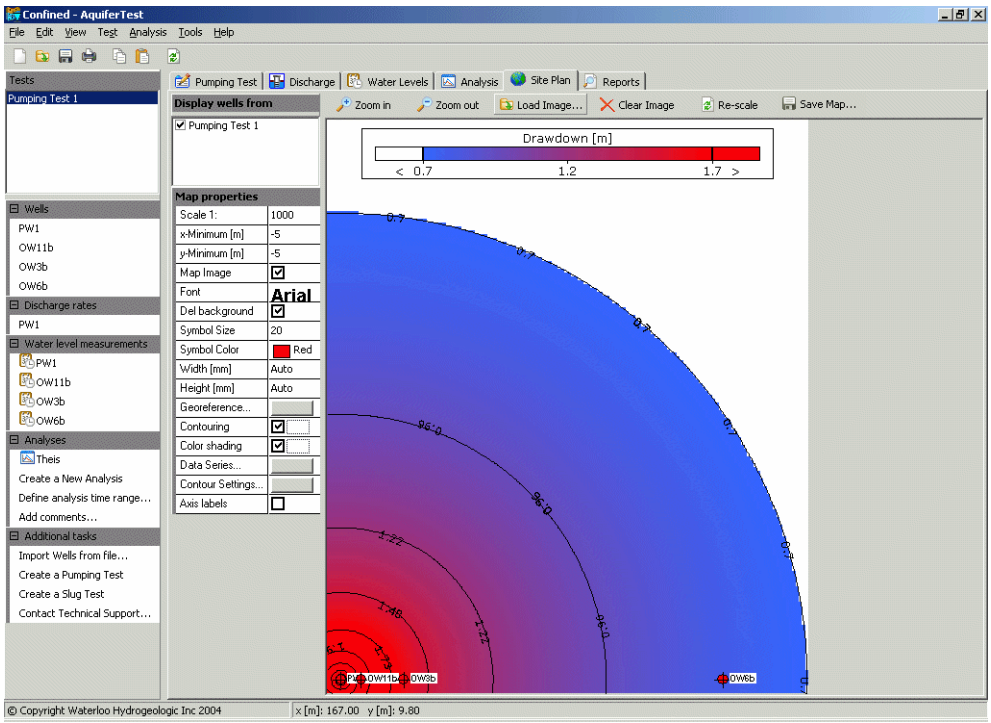
To modify the properties, click on the **Contour settings** button. In here, you can further customize your contours by changing the style and color of the lines, and customizing the well and label display as described above. In addition, you can modify the Data Series by selecting a different time duration, well, or analysis for which to calculate and grid the contours.

Try the following:

In the **Map Appearance** window,

- Define a **Minimum** value of 0.7 for the contour lines
- Define a **Minimum** value of 0.7 for the color shading
- Set the **Minimum** color shading to blue
- Set the < color shading to white
- Set the **Maximum** color shading to red
- Set the > color shading also to red

This will produce a map view similar to the one shown below.



If the edge of the colored field is too rough (i.e. appears as large steps), Click the **Data Series...** button and increase the number of **Rows** and **Columns** in the grid to make it finer.

This concludes the chapter on mapping and contouring.

7

Demonstration Exercises and Benchmark Tests

This chapter will explore many features of **AquiferTest** including various single and multiple pumping well solution methods, importing data from Excel and a datalogger file (.ASC), and planning a pumping test. The functionality of each feature is explained in detail in the following exercises:

- Exercise 1: Confined Aquifer - Theis Analysis
- Exercise 2: Leaky Aquifer - Hantush - Jacob Analysis
- Exercise 3: Recovery Data Analysis - Agarwal Solution
- Exercise 4: Confined Aquifer, Multiple Pumping Wells
- Exercise 5: Adding Data Trend Correction
- Exercise 6: Adding Barometric Correction
- Exercise 7: Slug Test Analysis

These exercises are designed to help you familiarize yourself with various functions of the program, but also to provide you with comparisons of the results obtained from **AquiferTest** to some other sources including published works and **AquiferTest 3.5**.

The sequence of a typical **AquiferTest** session is:

[1] Open or create a project

[2] Enter and/or import data and well information

[3] Select an analysis method

[4] Fit the type curve

[5] Print the output.

If **AquiferTest** is not already installed, follow the instructions found in Chapter 1: Introduction - “Installing AquiferTest” on page 8.

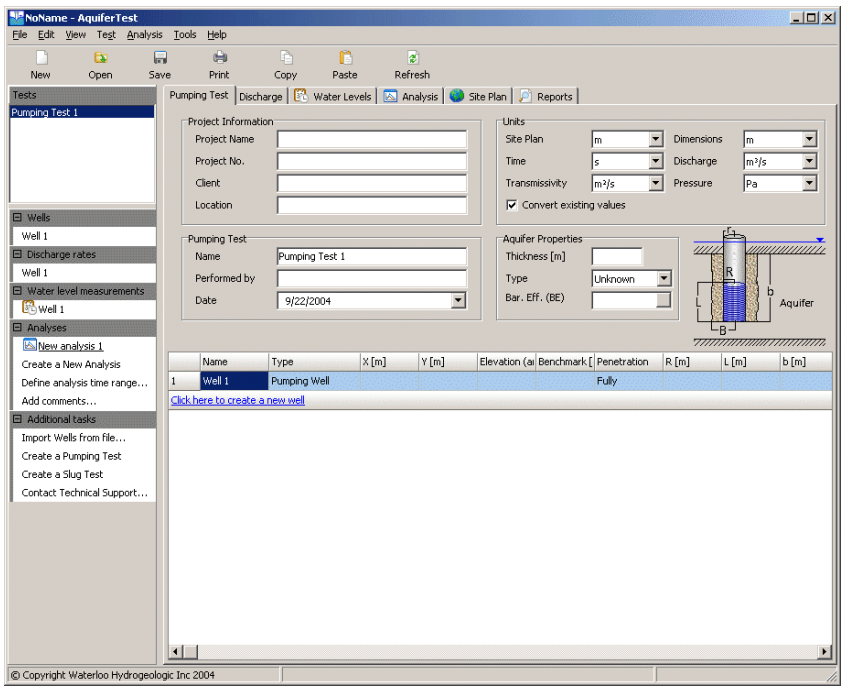
7.1 Exercise 1: Confined Aquifer - Theis Analysis

This exercise is designed to introduce you to the basic functions and pathways in **AquiferTest**. Go through this chapter carefully, taking note of the locations of different shortcuts, buttons, tabs, links, etc.

This exercise is based on the pumping test data published in Fetter, Applied Hydrogeology, 3rd Edition, 1994, p. 223.

[1] If you have not already done so, double-click the **AquiferTest** icon to start an **AquiferTest** session.

[2] When you launch an **AquiferTest** session, a blank project with the **Pumping Test** tab active loads automatically. The loaded page should look similar to the one shown below:



[3] In this step you will fill in the information needed for the project and/or the test. Not all information is required, however it is helpful in organizing tests and data sets.

In the **Project Information** frame enter the following:

- **Project Name:** Example 1
- **Project No.:** 1
- **Client:** ABC
- **Location:** Address, City, State/Province

In the **Pumping Test** frame enter the following:

- **Name:** Example 1: Theis Analysis
- **Performed by:** Your Name
- **Date:** Filled in automatically with the current date

HINT: To move from one data entry box to the next, use the Tab key or the arrow keys

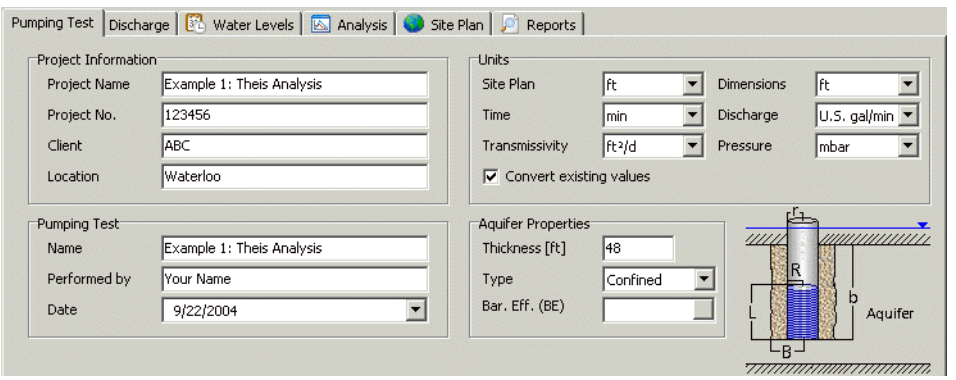
In the **Units** frame fill in the following:

- **Site Plan:** ft
- **Dimensions:** ft
- **Time:** min
- **Discharge:** US gal/min
- **Transmissivity:** ft^2/d
- **Pressure:** mbar

In the **Aquifer Properties** frame enter the following:

- **Thickness:** 48
- **Type:** Confined
- **Bar. Eff.:** leave blank

Your fields should now look similar to the figure below:



[4] All new projects have one default pumping well created in the **Wells** table (located in the bottom half of this window). Define the following well parameters for this well:

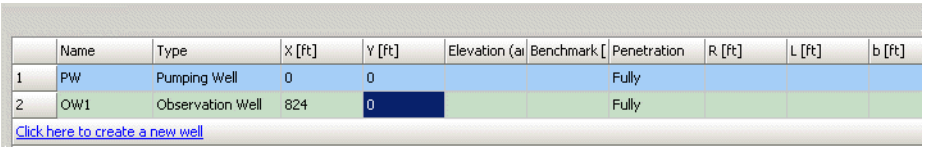
- **Name:** PW1
- **Type:** Pumping Well
- **X:** 0
- **Y:** 0

[5] "**Click here to create a new well"** link under the first well to create a new well. Define the following well parameters:

- **Name:** OW1

- **Type:** Observation Well
- **X:** 824
- **Y:** 0

The **Wells** table should now look similar to the following tab:



	Name	Type	X [ft]	Y [ft]	Elevation (a	Benchmark [	Penetration	R [ft]	L [ft]	b [ft]
1	PW	Pumping Well	0	0			Fully			
2	OW1	Observation Well	824	0			Fully			

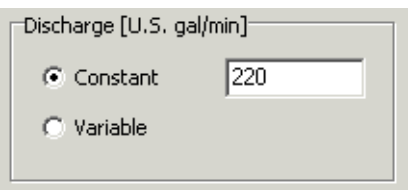
Click here to create a new well

NOTE: It is not necessary to enter well geometry data, since the Theis analysis assumes fully penetrating wells.

[6] Click on the **Discharge** tab to enter the discharge rate for the pumping well

[7] In the **Discharge** frame select the “Constant” option

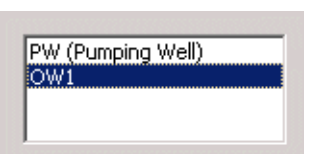
[8] Enter the following discharge rate: **220**.



NOTE: PW1 is highlighted in the window to the left of the **Discharge** frame. When there are multiple pumping wells in the test, the one that is highlighted is the one for which you are entering data; ensure that correct well is selected.

[9] Click on the **Water Levels** tab to enter the water level data for the observation well.

[10] In the box in the top left corner of the tab, select **OW1**, and ensure it is highlighted.



[11] In this exercise you will import data from an MSExcel file. From the main menu, select **File / Import / Water level measurements**.

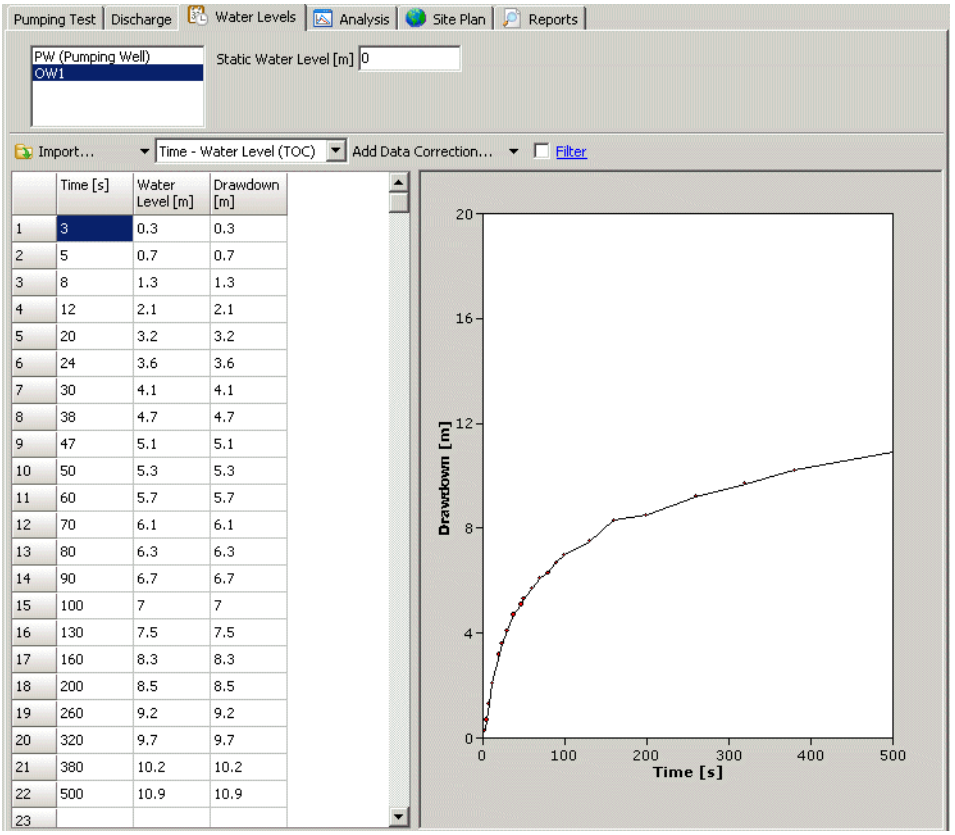
[12] Navigate to the folder “AquiferTest\ImportFiles\ and select the file **Exercise 1.xls**

[13] Click **Open**. The data should now appear in the time - water levels table.

[14] Type **0** in the **Static Water Level** field.

[15] Click on the (Refresh) button in the toolbar, to refresh the graph.

[16] You will see the calculated drawdown data appear in the **Drawdown** column and a drawdown graph displayed on the right.

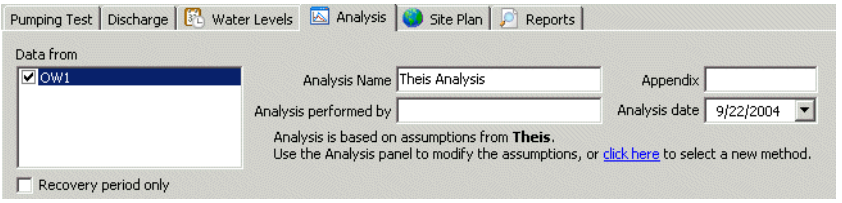


[17] Click on the **Analysis** tab

[18] In the **Data from** window, select **OW1**

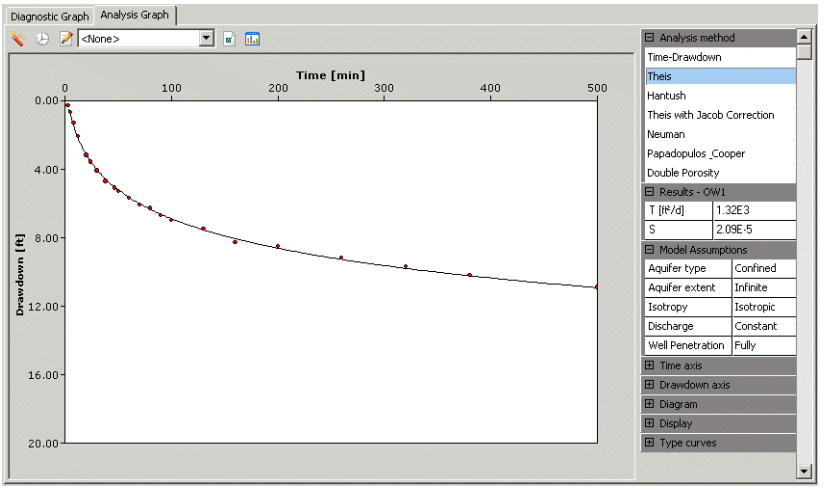
[19] In the **Analysis Name** field, type “Theis Analysis”. Your fields should now look

similar to the figure below

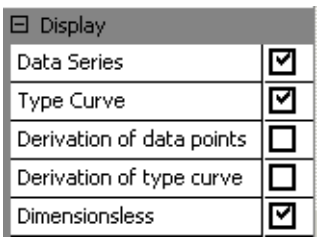


[20] Click on the

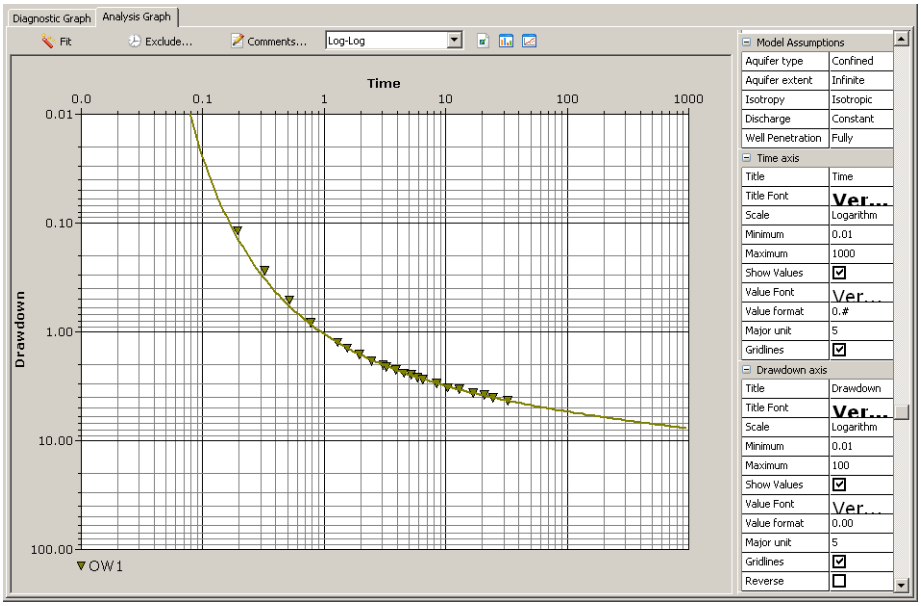
(Fit) icon, to fit the data to the type curve, and the analysis graph should appear, as shown below.



[21] To modify the plot axes, expand the **Display** frame of the **Analysis Navigator** panel and check the box beside **Dimensionless**



You should now see the following analysis graph.



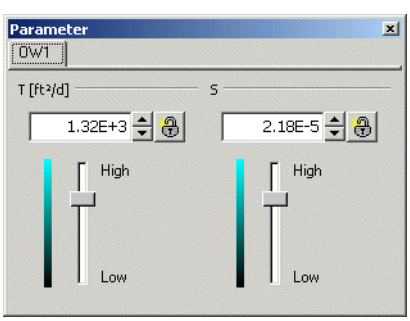
NOTE: You may need to adjust the **Min** and **Max** values for the **Time** and **Drawdown** axis.

[22] Click on the

(Automatic Fit) icon, to fit the data to the type curve.

[23] Click on the (Parameter Controls) icon to manually adjust the curve fit, and the calculated parameters.

[24] Use the sliders to adjust the parameters for **Transmissivity** and **Storativity**, or, if you notice that the increment is too large and your curve moves too quickly, type the new parameter values in the fields manually.



[25] When you have achieved the best fit between the fitted line and your data, close the parameter controls.

[26] The **Results** frame of the **Analysis navigator** displays the calculated values. These values should be approximately:

- Transmissivity = 1.32E+3 ft^2/d
- Storativity = 2.09E-5

Results - OW1	
T [ft²/d]	1.32E3
S	2.09E-5

The following table illustrates a comparison of these values, to that in **AquiferTest 3.5**, and with those published.

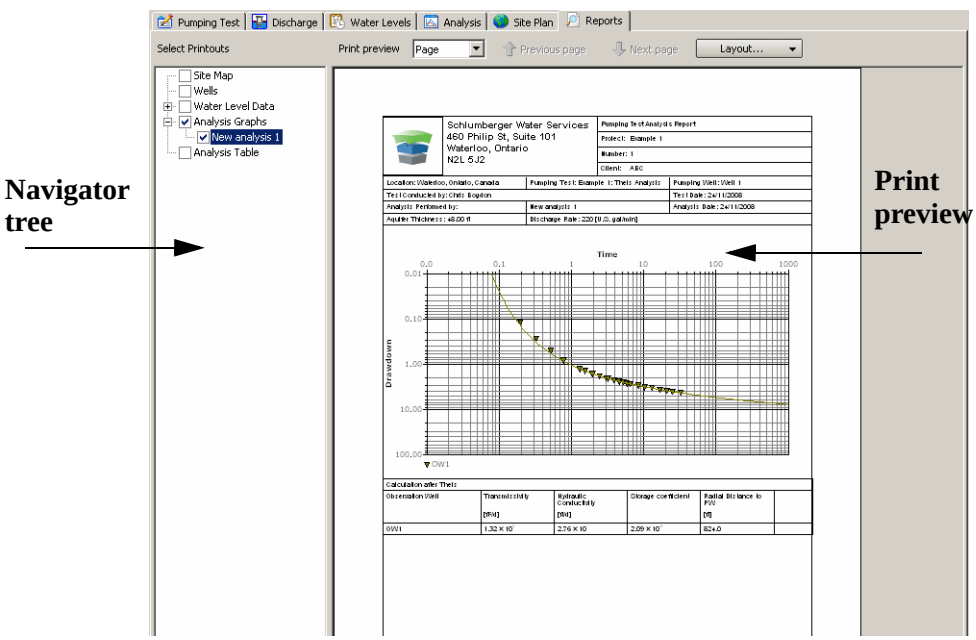
	AquiferTest 4.X	**AquiferTest 3.5**	**Published (Fetter, 1994)**
Transmissivity (ft2/d)	1.32 E+3	1.29 E+3	1.40 E+3
Storativity	2.09 E-5	2.18 E-5	2.40 E-5

[27] To print the analysis, click the **Reports** tab

[28] The navigation tree in the left portion of the tab lists all reports that are available for printing. Expand this tree.

[29] Under the **Analysis Graphs**, select the box beside “Theis Analysis”

[30] In the window to the right you will see the preview of the print-out



You can define your company information and logo under **Tools / Options.**

[31] Click on the (**Print)** button in the tool bar, or select **File/Print** from the main menu.

[32] Save your project by selecting **File/Save As**, and define a project name (Example 1).

This concludes the exercise on the Theis analysis. In the next exercise you will analyze data using a method. You have a choice of exiting **AquiferTest** or continuing on to the next exercise.

7.2 Exercise 2: Leaky Aquifer - Hantush - Jacob Analysis

This exercise is written with the assumption that you have gone through the first exercise, and are familiar with the **AquiferTest** interface.

This exercise is based on the pumping test data published in Dawson and Istok, Aquifer Testing: Design and Analysis of pumping and slug tests, 1991, p. 113

[1] Launch **AquiferTest** or, if you already have the window open, create a new project by clicking the (**New**) button from the toolbar or select **File/New** from the main menu.

[2] In the **Pumping Test** tab, enter the following information in the appropriate fields:

Project Information:

- **Project Name:** Exercise 2
- **Project No:** 2
- **Client:** ABC
- **Location:** Your Town

P**umping Test** frame:

- **Name:** Hantush-Jacob Analysis
- **Performed by:** Your Name
- **Date:** fills in automatically

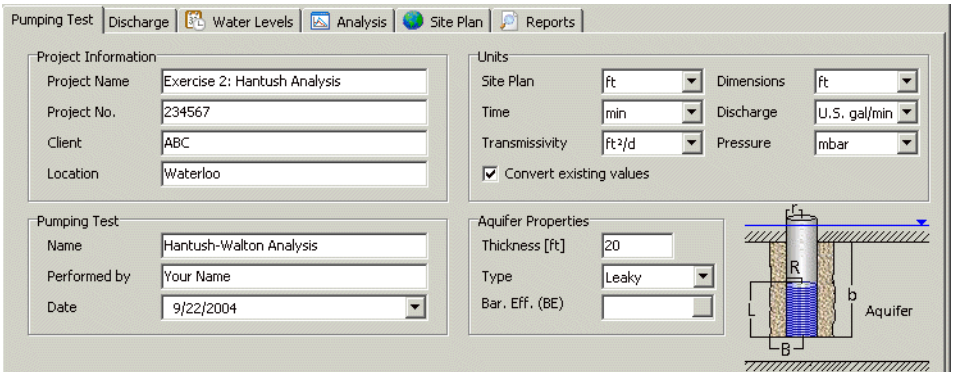
Units frame

- **Site Plan:** ft
- **Dimensions:** ft
- **Time:** min
- **Discharge:** US gal/min
- **Transmissivity:** US gal/d-ft

Aquifer Thickness frame

- **Thickness:** 20
- **Type:** Leaky
- **Bar. Eff.:** leave blank

Your fields should now look similar to the figure shown below:



[3] In the **Wells** tab, a pumping well has been created by default. Set the parameters for that well as follows:

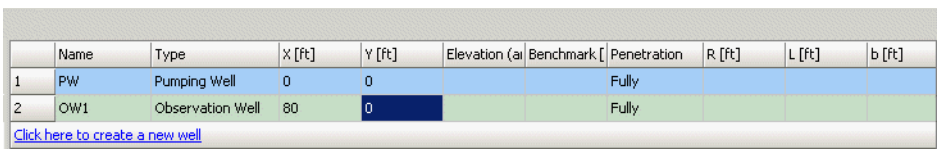
- **Name:** PW
- **Type:** Pumping Well
- **X:** 0
- **Y:** 0

[4] Create another well by clicking the **Click here to create a new well** link under the first well

[5] Set the parameters for the new well as follows:

- **Name:** OW1
- **Type:** Observation Well
- **X:** 80
- **Y:** 0

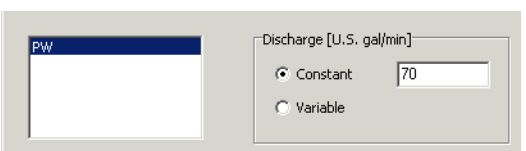
Your **Wells** grid should now look similar to the following figure:



[6] Click on the **Discharge** tab to enter discharge data for the pumping well

[7] In the **Discharge** frame select the radio button beside “Constant”

[8] Enter **70** in the field to the right.



[9] Click the **Water Levels** tab to enter the water level data for the observation well. In this example you will cut-and-paste data from a data file.

[10] In the window in the top left corner highlight "**OW1**"

[11] Minimize **AquiferTest**, and browse to the folder "AquiferTest\ImportFiles\ and select the file **Exercise 2.xls.**

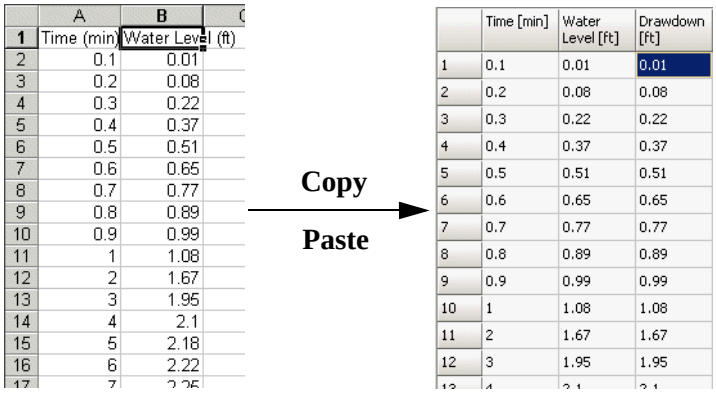
[12] Double-click on this file, to open it in MS Excel

[13] Select the first two columns of data, and **Copy** this onto the Windows clipboard

[14] Minimize MS Excel and Maximize the **AquiferTest** window

[15] Activate the **Water Levels** tab

[16] Right-click on the first cell in the Time Water Level grid, and select **Paste**



	A	B
1	Time (min)	Water Level (ft)
2	0.1	0.01
3	0.2	0.08
4	0.3	0.22
5	0.4	0.37
6	0.5	0.51
7	0.6	0.65
8	0.7	0.77
9	0.8	0.89
10	0.9	0.99
11	1	1.08
12	2	1.67
13	3	1.95
14	4	2.1
15	5	2.18
16	6	2.22

	Time [min]	Water Level [ft]	Drawdown [ft]
1	0.1	0.01	0.01
2	0.2	0.08	0.08
3	0.3	0.22	0.22
4	0.4	0.37	0.37
5	0.5	0.51	0.51
6	0.6	0.65	0.65
7	0.7	0.77	0.77
8	0.8	0.89	0.89
9	0.9	0.99	0.99
10	1	1.08	1.08
11	2	1.67	1.67
12	3	1.95	1.95

[17] Enter 0 in the **Static Water Level** field.

[18] Click on the (Refresh) button in the toolbar, to refresh the graph. The calculated drawdown appears in the **Drawdown** column and a graph of the drawdown appears to the right of the data.

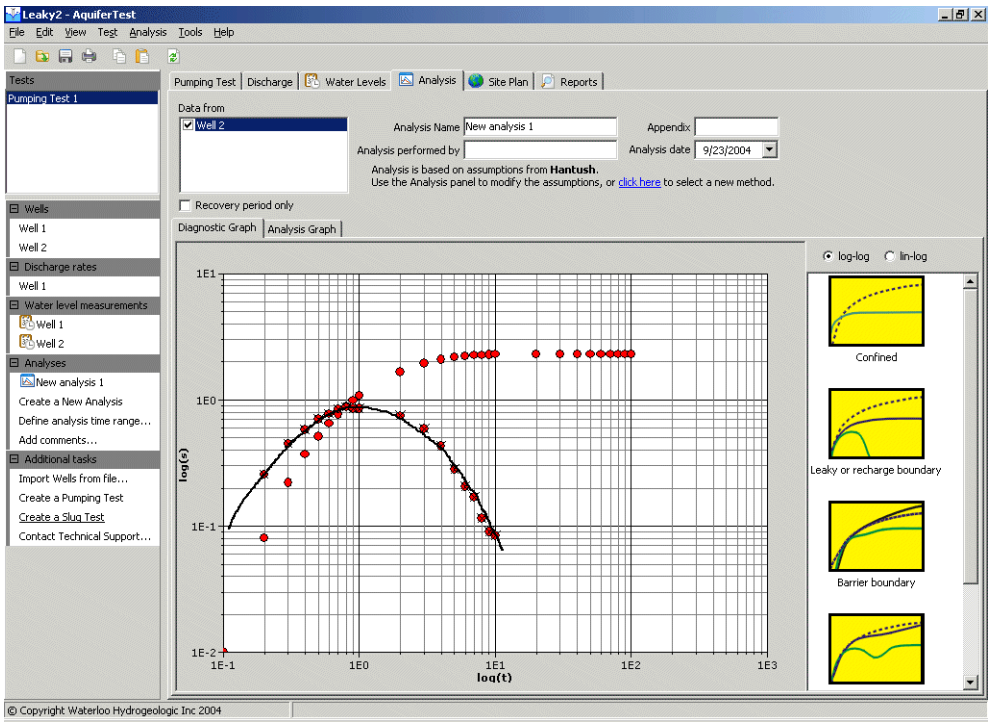
[19] Click on the **Analysis** tab

[20] Check the box beside **OW1** in the **Data from** window.

If you are not sure whether the aquifer is leaky or not, you can use the Diagnostic Plots, and analyze the drawdown derivative data, to provide insight on the pumping test activities. This is demonstrated below.

[21] Click on the **Diagnostic Graph** tab in the Analysis plot, and the following

window will appear.



In this image, you can see the observed drawdown data, and the calculated derivative data. The derivative data is distinguished by an X through the middle of each data symbol, and is delineated in the image above.

To the right of the graph window, you will see 5 yellow diagnostic plot windows, with a variety of type curves. The plots are named diagnostic, since they provide an insight or “diagnosis” of the aquifer type and conditions. Each plot contains theoretical drawdown curves for a variety of aquifer conditions, well effects, and boundary influences, which include:

- Confined
- Leaky/Recharge Boundary
- Barrier Boundary
- Double Porosity or Unconfined
- Well Effects (WellBore storage).

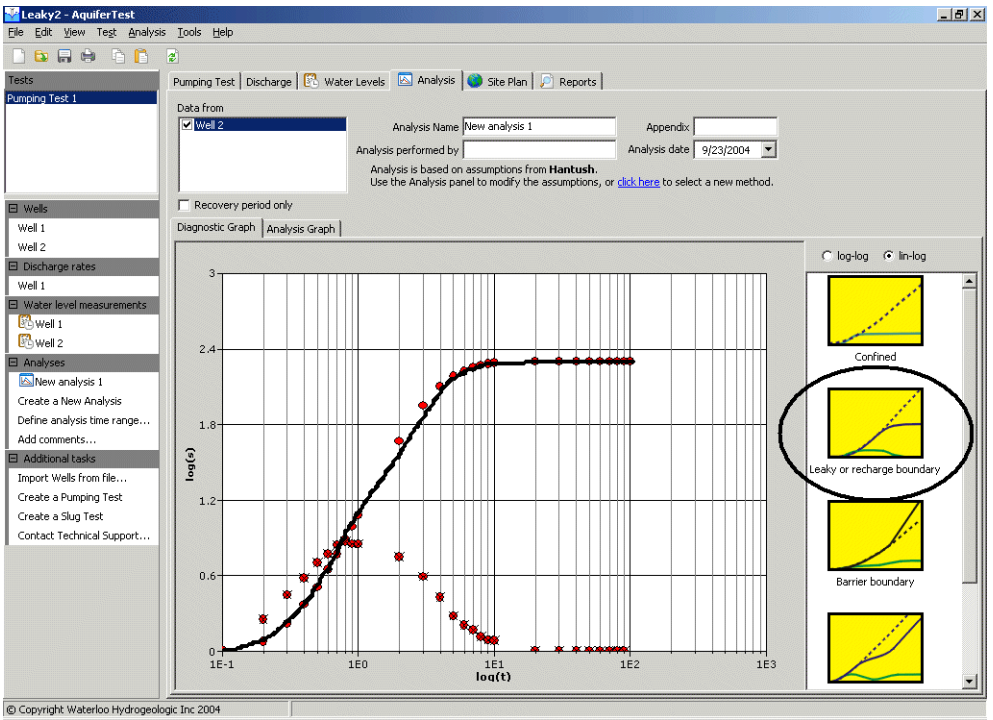
Each diagnostic graph contains 3 lines:

- Theis type curve (dashed black line)
- Theoretical drawdown curve under the expected conditions (solid black line)
- Drawdown derivative curve (solid green line).

These plots can be displayed on a log-log or semi-log scale, by selecting the appropriate radio button above the diagnostic graphs. For this example, the aquifer type is not immediately evident upon inspection of only the drawdown

data. However, if you look at the derivative data, you can see the characteristic “saddle”, typical of a leaky aquifer (outlined in the image above). Alternately, you can use the semi-log diagnostic graph to interpret the aquifer conditions.

[22] Lin-Log radio button above the yellow diagnostic graphs. The following window will appear.



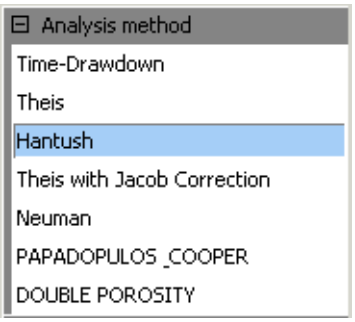
In the Semi-Log plot, you can compare the observed drawdown curve to the diagnostic plots. In this example, it is evident that the observed drawdown curve (outlined in the image above) is very similar to that expected in a Leaky aquifer (refer to the theoretical drawdown curve in the second diagnostic graph, circled above). For more details on the diagnostic graphs, see Chapter 4: Diagnostic Plots.

Now that you are confident that the aquifer is leaky, you can select the appropriate solution method, and calculate the aquifer parameters.

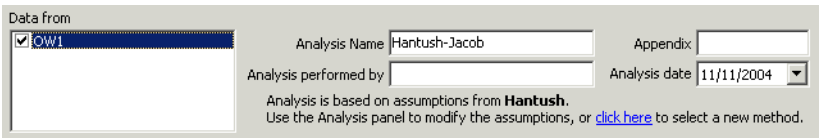
[23] Click on the **Analysis Graph** tab

[24] Select “Hantush” from the **Analysis methods** frame of the **Analysis navigator**

panel



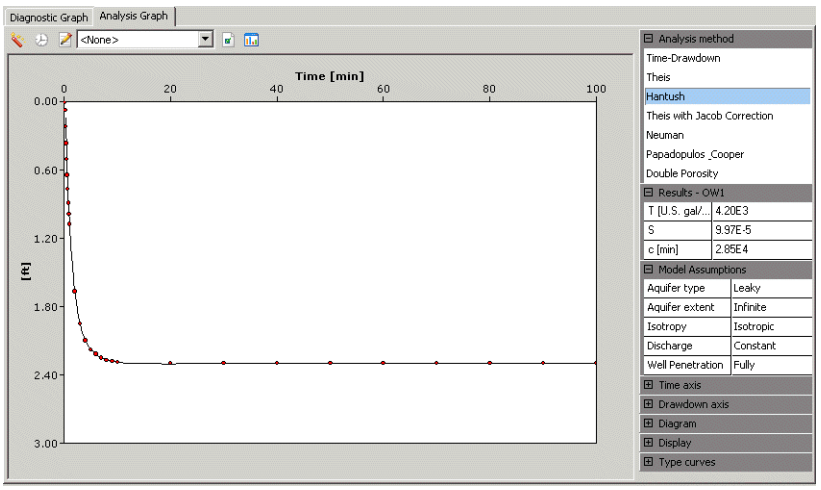
[25] In the **Analysis Name** field enter “Hantush-Jacob”



[26] Click on the

(Fit) icon, to fit the data to the type curve. The analysis graph should appear similar to below:

[27] If you are not satisfied with the fit, use **Parameter Controls** to adjust the curve



To view the Dimensionless (Type Curve) view, expand the **Display** frame of the **Analysis Navigator** panel and check the box beside **Dimensionless.** This option is not demonstrated in this Exercise.

[28] The **Results** frame of the **Analysis navigator** displays the calculated values. These values should be approximately:

- Transmissivity = 4.20E+3 US gal/d-ft
- Storativity = 9.97E-5

- Hydraulic resistance = 2.85E+4

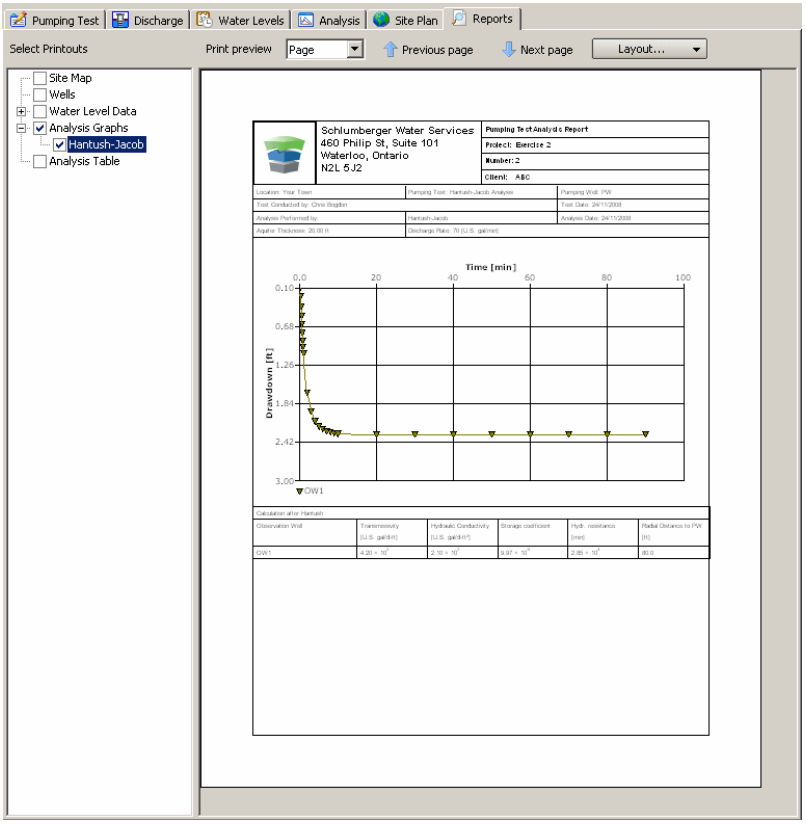
The following table illustrates a comparison of these values, to that in **AquiferTest 3.5**, and with those published.

	AquiferTest 4.X	**AquiferTest 3.5**	**Published (Dawson, 1991)**
Transmissivity (US gal/d-ft)	4.20 E+3	6.1 E+3	4.11 E+3
Storativity	9.97 E-5	9.08 E-6	9.50 E-6

[29] To print your report, click on the **Reports** tab

[30] Expand the Navigator tree in the left portion of the **Reports** tab

[31] Check the box beside the "Hantush-Jacob" under **Analysis Graphs**



[32] Click on the (Print) button in the tool bar, or select **File/Print** from the main menu.

[33] Save your project by clicking on the (Save) icon or selecting **File/Save as**

The next exercise will demonstrate analysis of recovery data from a pumping test, using the Agarwal solution. You have the option to exit the program (make sure you save the changes) or to continue on to the next exercise.

7.3 Exercise 3: Recovery Data Analysis - Agarwal Solution

This exercise demonstrates analysis of recovery data, using the Agarwal solution, new to **AquiferTest.** In addition, the Data Logger Wizard feature will be demonstrated. This exercise assumes that you are familiar with the program interface; feel free to return to Exercise 1 for the basics on navigating **AquiferTest**.

[1] Start **AquiferTest** or, if you already have the program open, create a new project.

[2] In the **Pumping Test** tab enter the following information:

Project Information frame

- **Project name:** Exercise 3: Agarwal Recovery
- **Project No.:** 3
- **Client:** ABC
- **Location:** Your Town

Pumping Test frame

- **Name:** Agarwal Recovery
- **Performed by:** Your Name
- **Date:** filled in automatically

Units frame

- **Site Plan:** m
- **Dimensions:** m
- **Time:** s
- **Discharge:** m^3/s
- **Transmissivity:** m^2/s

Aquifer Properties frame

- **Aquifer Thickness**: 20 m

[3] The new project will contain one pumping well, by default. Set the parameters for this well as follows:

Well 1

- **Name:** PW
- **Type:** Pumping Well
- **X:** 0
- **Y:** 0

Next, create a new well. Click on the "**Click here**" link to add a new well to the table. Define the parameters for this new well, as follows:

Well 2

- **Name:** OW1
- **Type:** Observation well
- **X:**10
- **Y:** 0

[4] Click on the **Discharge** tab

[5] Select **Constant** discharge

[6] Enter the value **0.0015** in the field beside

[7] Click on the **Water Levels** tab

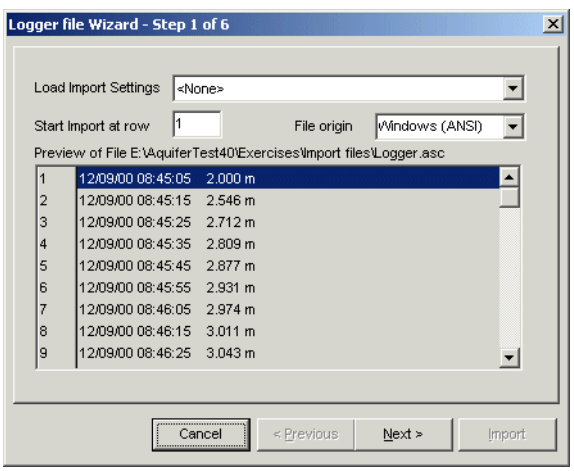
[8] Highlight "**OW1**" in the wells list in the top left corner of the tab. For this well, you will import the time-water level data from a data logger file.

[9] Select **File/Import/Data Logger file** from the main menu

[10] Browse to the folder "AquiferTest\ImportFiles\ and select the **Exercise3.asc** file.

[11] Highlight the file and click **Open**. This will launch the 6-step data logger import wizard.

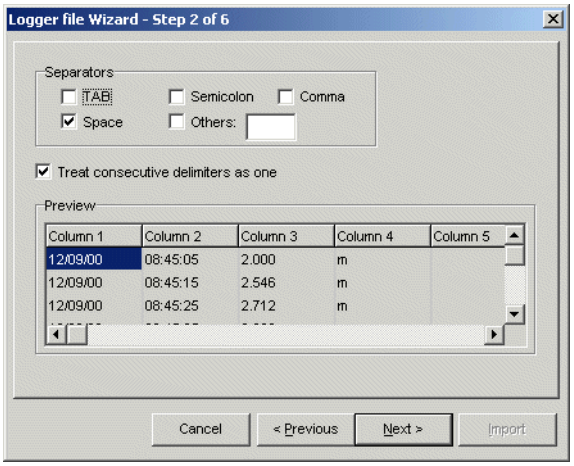
[12] In the first step, select a set of settings saved in a previous import session. This is a great time saver when importing many files with similar format. Since there are no existing settings, you define the required settings manually.



The first window also allows you to select the row from which to start importing. If you have headers in the first row you can start importing from row 2. There are no headers in this file so you can leave everything as it is.

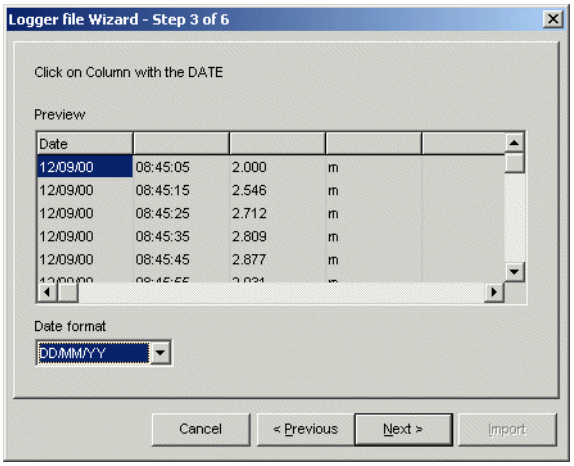
Click **[Next]**.

[13] In Step 2, specify the delimiters. Un-check the box beside **Tab** and check the one beside **Space**.



Click **[Next]**

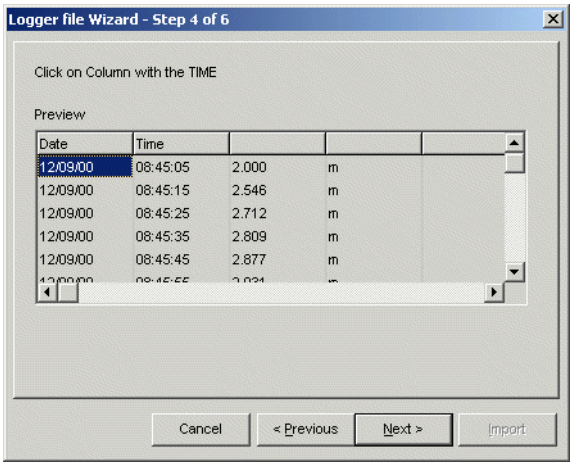
[14] In Step 3, specify the **Date** column and the format in which the date is entered. Click on the first column to mark it as **DATE** and in the drop-down menu below choose **DD/MM/YY**. Your screen should look similar to the one shown below.



Click **Next**

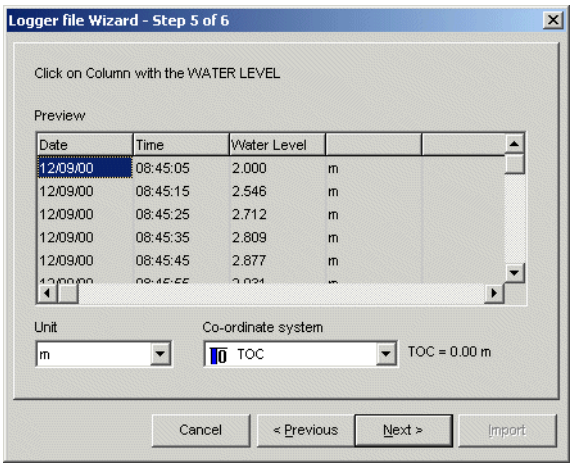
[15] In Step 4, specify the **Time** column. Click on the header above the second

column.



Click **[Next]**

[16] In Step 5, specify the **Water Level** column. Click on the header above the third column. Use the default units of m (meters).

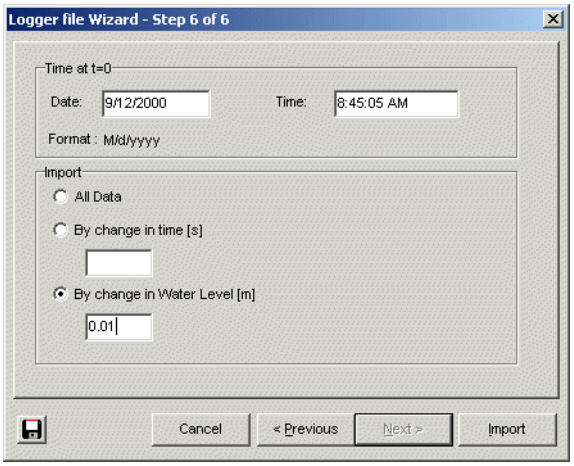


In addition, use the default co-ordinate system of Top of Casing Datum.

Click **[Next]**.

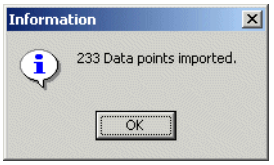
[17] In Step 6, there are options to specify the start time, and data filtering options. The data loggers usually record measurements at pre-set time intervals and as such, record many repetitive water level measurements. To import so much redundant data slows down the processing speed. The data can be filtered by time or by change in water level.

Select the radio button beside the **By change in depth to WL** and enter **0.01**.



Click **[Import]**

[18] A dialog box will appear, indicating 233 data points have been imported.



Click **OK**

[19] Enter **Static Water level** as 2.0

[20] Click on the (Refresh) button in the toolbar, to refresh the graph. The calculated drawdown appears in the **Drawdown** column and a graph of the drawdown appears to the right of the data.

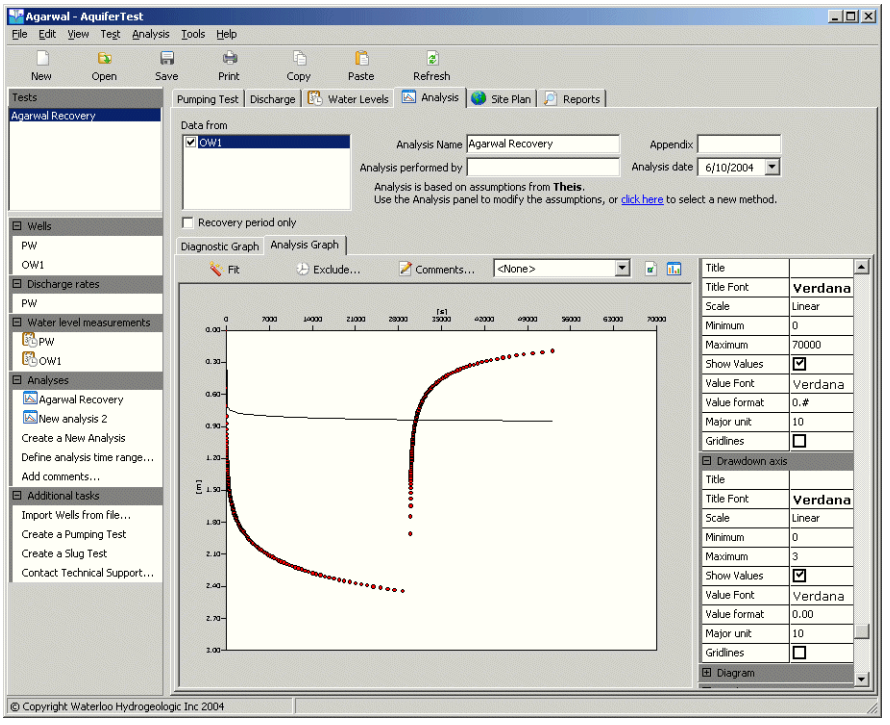
[21] Move to the **Analysis** tab.

[22] Select **OW1** from the **Data from** window

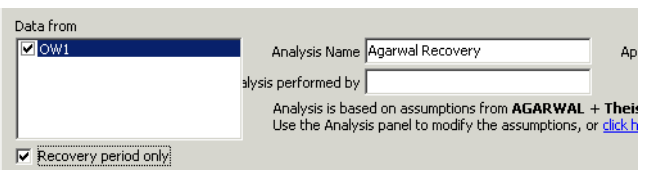
[23] In the **Analysis Name** field, type "**Agarwal Recovery**"

[24] The graph below shows the Drawdown and recovery data

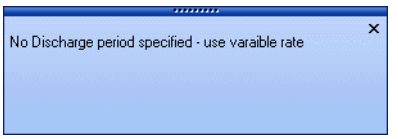
.



[25] Check the box beside the **Recovery period only** under the **Data from** window


Data from
OW1
Analysis Name Agarwal Recovery
Ap
alysis performed by
Analysis is based on assumptions from AGARWAL + Theis
Use the Analysis panel to modify the assumptions, or click h
Recovery period only

[26] A following message will appear:



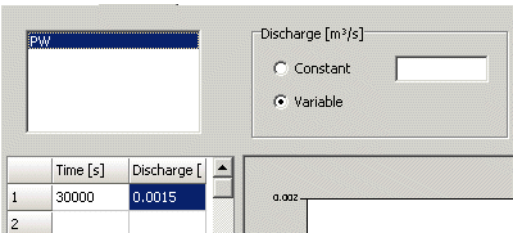
The recovery test requires that you define the time when the pumping stopped. To do this, use the variable discharge rate option as described below.

[27] Return to the **Discharge** tab

[28] Select **Variable** in the **Discharge** frame

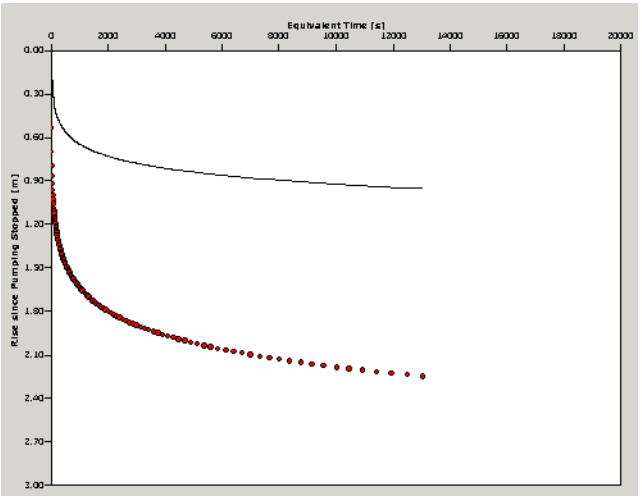
[29] For this pumping test, the pump was shut off after 30,000 s. In the first cells of the

Time and **Discharge** columns type in 30000 and 0.0015 respectively.



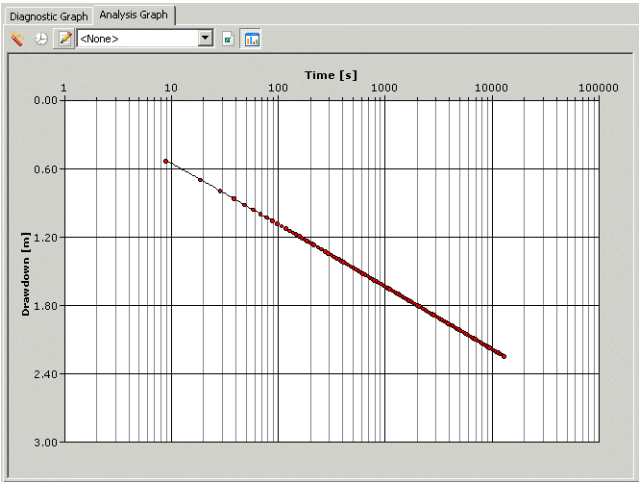
[30] Return to the **Analysis** tab

[31] You can see that the graph has refreshed, displaying only the recovery portion of the data.



[32] Change the **Scale** of the **Time axis** to “logarithm”

[33] Press the **Fit** button to perform autofit to the data.



[34] The data and the curve fit quite well together, however if you wish you can use the **Parameter Controls** to manually adjust the curve fit.

[35] The calculated parameter values should be similar to the following:

Transmissivity = 5.01 E-4 m2/s

Storativity = 1.17 E-5

The following table illustrates a comparison of these values (using the Agarwal solution), to that obtained in **AquiferTest 3.5** (using the Theis Recovery solution).

	AquiferTest 4.X (Agarwal)	**AquiferTest 3.5 (Theis Recovery)**
Transmissivity (m2/s)	5.01 E-4	5.02 E-4
Storativity	1.17 E-5	N/A*

*One of the major advantages of the Agarwal solution, is that it provides a calculation for the storativity parameter; this was not possible with the Theis Recovery solution, in **AquiferTest 3.5**.

[36] Print the desired reports by selecting the **Reports** tab and checking the boxes beside the reports you wish to print.

[37] Click on the (Print) button in the tool bar, or select **File/Print** from the main menu.

[38] Save your project by clicking on the (Save) icon or selecting **File/Save as** from the main menu.

This concludes the exercise. The next exercise will deal with multiple pumping wells. You have the choice of exiting **AquiferTest** or proceeding to the next exercise.

7.4 Exercise 4: Confined Aquifer, Multiple Pumping Wells

In this exercise you will learn how to use **AquiferTest** to not only determine aquifer properties using discharge and drawdown data, but also how to use these values to predict the effect that an additional pumping well will have on drawdown at the observation well, and also, how to predict the drawdown in a well at any point in the effective area of the pumping well(s).

This exercise is divided into 3 sections: To begin, you will create a Theis analysis to determine the aquifer parameters. Then, you will examine the effect a second pumping well will have on the drawdown at the observation well used in the first section. Finally, you will predict the drawdown at a well at any point in the effective radius of the pumping wells.

7.4.1 Determining Aquifer Parameters

[1] Start **AquiferTest** or, if you already have it open, create a new project.

[2] Complete the fields in the pumping test tab, as follows:

Project Information frame

- **Project Name:** Exercise 4
- **Project No.:** 4
- **Client:** ABC
- **Location:** Your Town

Pumping Test frame

- **Pumping Test:** Theis - Multiple Pumping Wells
- **Performed by:** Your Name
- **Date:** filled in automatically

Units frame

- **Site Plan:** ft
- **Dimensions:** ft
- **Time:** min
- **Discharge:** US gal/min
- **Transmissivity:** ft^2/d

Aquifer Properties frame

- **Thickness:** 40
- **Aquifer Type:** Unknown

[3] In the **Wells** table, complete the following information for the first (pumping) well:

Well 1

- **Name:** Water Supply 1
- **Type:** Pumping Well
- **X:** 350
- **Y:** 450
- **L:** 50
- **r:** 0.25
- **R:** 0.3

Next, create two additional wells.

Click **Click here to create a new well**, to add a new pumping well

Well 2

- **Name:** Water Supply 2
- **Type:** Not Used (this pumping well will be activated later in the exercise)
- **X:** 350
- **Y:** 100
- **L:** 50
- **r:** 0.25
- **R:** 0.3

Click **Click here to create a new well**, to add a new observation well

Well 3

- **Name:** OW-1
- **Type:** Observation Well
- **X:** 350
- **Y:** 250
- **L:** 50
- **r:** 0.05
- **R:** 0.06

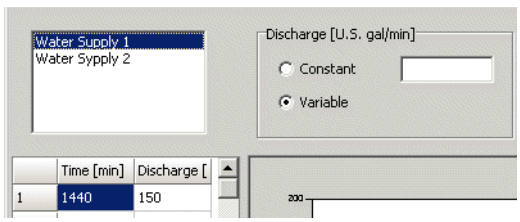
[4] Click on the **Discharge** tab

[5] Select **Water Supply 1** from the well list

[6] Select **Variable** in the **Discharge** frame

[7] Enter following values in the **Discharge Table**:

Time	**Discharge**
1440	**150**



[8] Click on the **Water Levels** tab.

[9] Select **OW1** from the well list. For this exercise, the data set will be imported from an excel file.

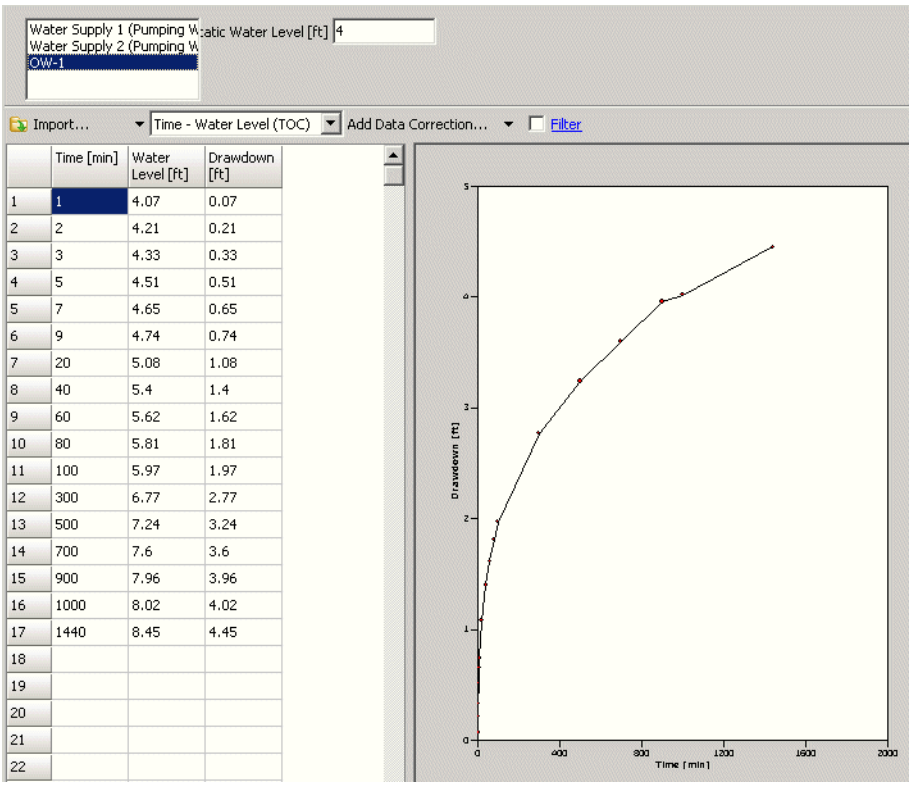
[10] From the main menu, select **File/Import/Water Level measurements**.

[11] Browse to the folder "AquiferTest\ImportFiles\ and select the file **Exercise4.xls.**

[12] Click **[Open]**

[13] Enter **Static Water Level** of 4.0

[14] Click on the (Refresh) button in the toolbar, to refresh the graph. The calculated drawdown appears in the **Drawdown** column and a graph of the drawdown appears to the right of the data.



	Time [min]	Water Level [ft]	Drawdown [ft]
1	1	4.07	0.07
2	2	4.21	0.21
3	3	4.33	0.33
4	5	4.51	0.51
5	7	4.65	0.65
6	9	4.74	0.74
7	20	5.08	1.08
8	40	5.4	1.4
9	60	5.62	1.62
10	80	5.81	1.81
11	100	5.97	1.97
12	300	6.77	2.77
13	500	7.24	3.24
14	700	7.6	3.6
15	900	7.96	3.96
16	1000	8.02	4.02
17	1440	8.45	4.45
18			
19			
20			
21			
22			

[15] Select the **Analysis** tab

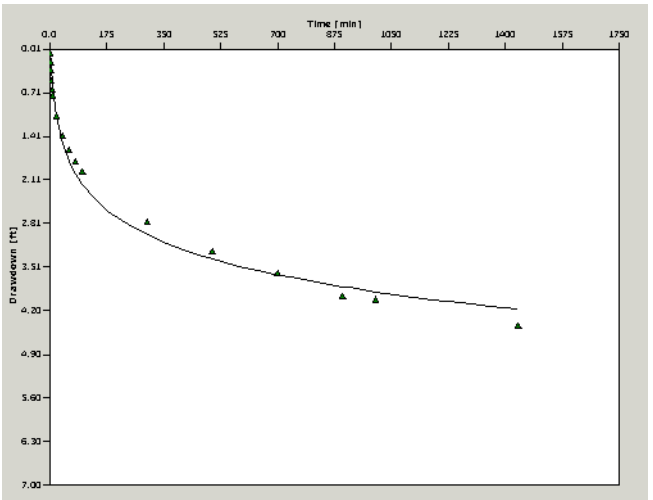
[16] Select "**OW-1**" in the **Data from** window

[17] Click on the

(Automatic Fit) icon, to fit the data to the type curve.

The calculated parameter values should be:

- Transmissivity = 3.02 E3 ft2/d
- Storativity = 7.06E-4

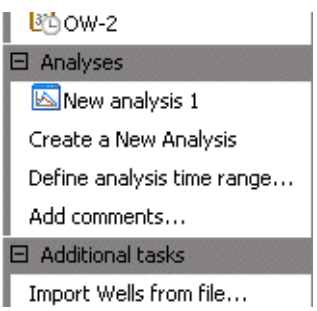


[18] Since the automatic fit uses all data points, often it does not provide the most accurate results. For example you may wish to place more emphasis on the early time data if you suspect the aquifer is leaky or some other boundary condition is affecting the results.

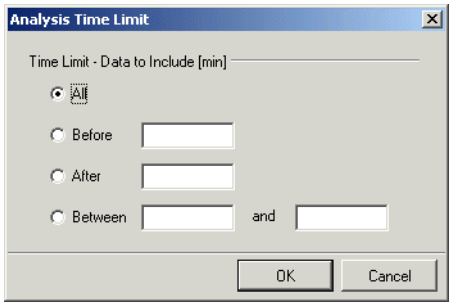
In this case, there is a boundary condition affecting the water levels / drawdown between 700 - 1000 feet south of **Water Supply 1**. You need to remove the data points after time = 100 minutes.

There are several ways to do this, either by de-activating data points in the analysis (they will remain visible but will not be considered in analysis) or by applying a time limit to the data (data outside the time limit is removed from the display).

You will examine both options. From the Main menu bar, select **Analysis** / **Define analysis time range,** or select this option from the **Analysis** frame of the **Project Navigator** panel



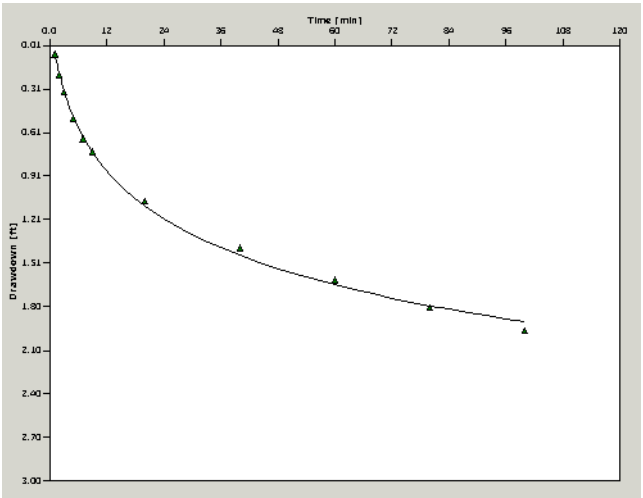
The following dialogue will be produced:



[19] Select "**Before**" and type in **101**. This will include all the data-points before 101 minutes and will remove all the data-points after that period.

Click **[OK]**.

[20] Click the **Automatic Fit** icon and see how the graph has changed. The points after 100 minutes are no longer visible (change the axes' **Min** and **Max** values if necessary to see the effect).



[21] The parameters in the **Results** frame have changed to

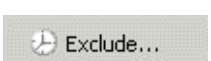
- Transmissivity = 4.48E3
- Storativity = 4.27E-4

[22] Now restore the graph to normal: select **Define analysis time range** again and selecting **All**.

Click **[OK].**

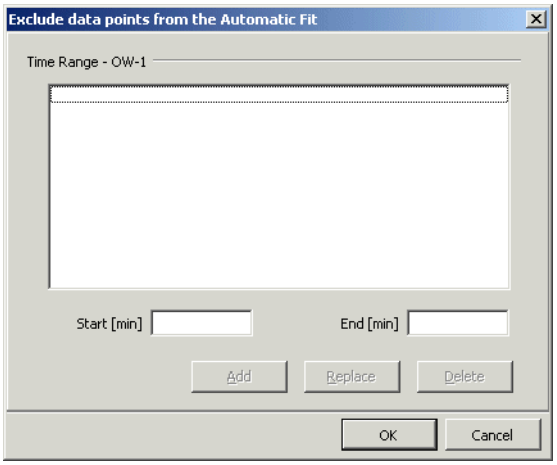
[23] Click on the

(Automatic Fit) icon, to fit the data to the type curve.

[24] You will now exclude the points. Click 

(Exclude) icon above

the graph. The following dialogue will appear:

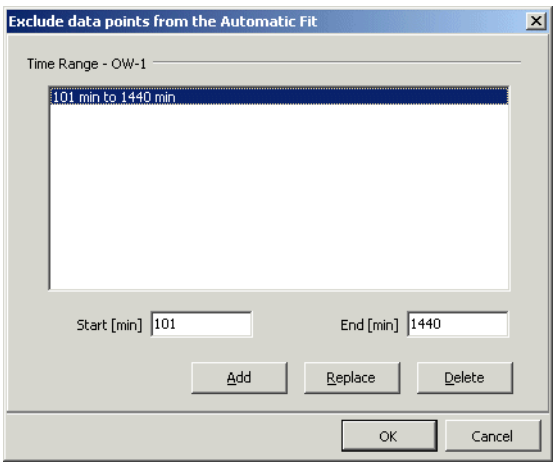


[25] Type in **101** in the "**Start**" field and **1440** in the "**End**" field.

Click **[Add]**

[26] Highlight the added time range.

Click **[OK]**



[27] Click on the

(Fit) icon, to fit the data to the type curve.

[28] The curve change is identical to the "Define analysis time range" option (as evident from the calculated parameters in **Results** frame), however the points are still visible on the analysis graph.

[29] The parameters in the **Results** frame should now be similar to the following:

- Transmissivity = 4.48E3
- Storativity = 4.27E-4

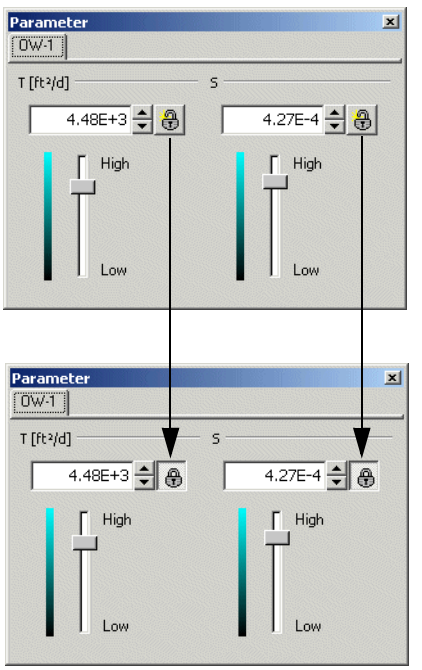
7.4.2 Determining the Effect of a Second Pumping Well

In this section, the second pumping well will be activated, and **AquiferTest** will predict the drawdown that would occur as a result of two pumping wells running simultaneously.

In the previous section, the aquifer parameters (Transmissivity and Storativity) were calculated with the Theis method. In order to maintain these values, you need to "lock" the parameters.

[30] Click on the **Parameter Controls** icon, or select **View / Analysis Parameters** from the main menu.

[31] Click on the both "padlock" icons beside the parameters.



[32] Click on the **[X]** button to close the Parameters dialog

[33] Click on the **Pumping Test** tab

[34] In the **Wells** table, select **WaterSupply2** from the well list

[35] To "turn on" the second pumping well, change the type from **Not Used** to **Pumping Well**

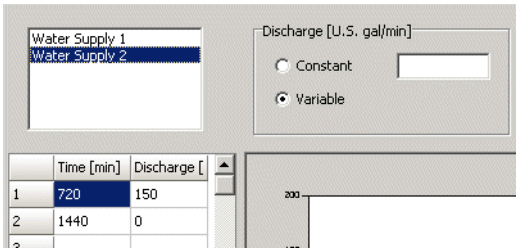
[36] Click on the **Discharge** tab

[37] Select **WaterSupply2** from the well list

[38] Select the **Variable** discharge option

[39] Enter the following values in the table:

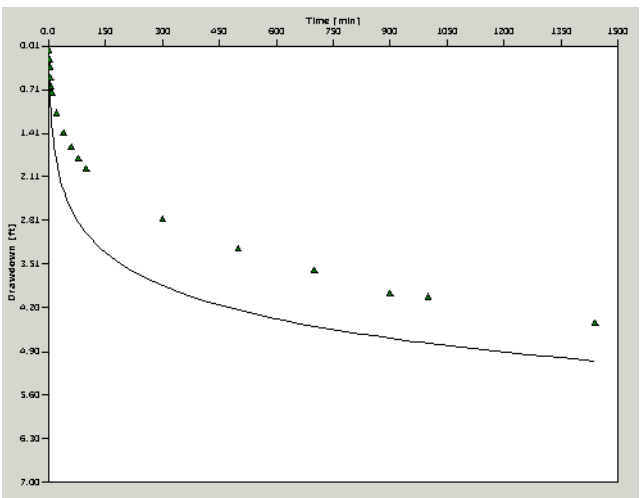
Time	Discharge
720	150
1440	0



These values indicate that the **Water Supply 2** well was turned on at the same time as the **Water Supply 1**, however, whereas **Water Supply 1** pumped for 1440 minutes (24 hours) at a constant discharge of 150 US gal/min, **Water Supply 2** only ran at that rate for 720 minutes (12 hours) and was then shut off.

[40] Select the **Analysis** tab

[41] You will see that the theoretical drawdown curve no longer goes through the observed points; instead the curve is below the data, indicating that the predicted drawdown at OW1 has increased as a result of activating the second pumping well.

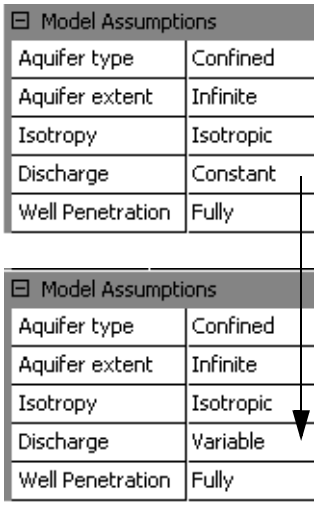


AquiferTest calculates the theoretical drawdown curve, using the Transmissivity (T) and Storativity (S) values calculated earlier in this exercise.

[42] The Theis analysis assumes a Constant discharge, however, **AquiferTest** allows you to change the model assumptions in the tests, as you will do now.

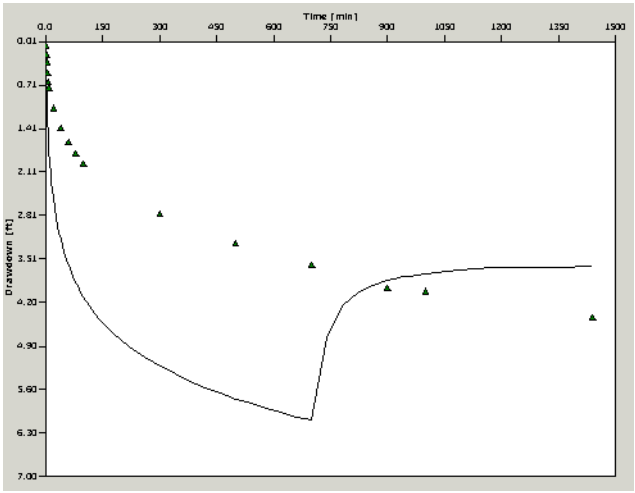
[43] Expand the **Assumptions** frame of the **Analysis Navigator**

[44] In the drop-down menu beside "**Discharge**" change "**Constant**" to "**Variable:** ,



and click anywhere in the **Assumptions** panel to apply the changes.

[45] You will notice that now at 720 minutes the curve rises sharply which is equivalent to a sudden decrease in drawdown. This coincides with WaterSupply2 being shut off after 720 minutes. As a result, the total discharge from the two wells decreases to 150 gpm (from 300 gpm) and the resulting drawdown is less.



NOTE: You may need to modify the max value for the drawdown axis to see the entire curve.

Using this procedure, AquiferTest allows you to predict the effect of any number of pumping wells on the drawdown at a well.

7.4.3 Predicting Drawdown at Any Distance from the Pumping well

In this section, an imaginary observation well will be added at the property border, close to the pumping test site. The following procedure will allow you to predict the drawdown at that well (or any well at a given set of coordinates).

[46] Return to the **Pumping Test** tab, and locate the **Wells** table.

Create a well with the following parameters:

- **Name:** OW-2
- **Type:** Observation Well
- **X:** 700
- **Y:** 850
- **L:** 50
- **r:** 0.25
- **R:** 0.30

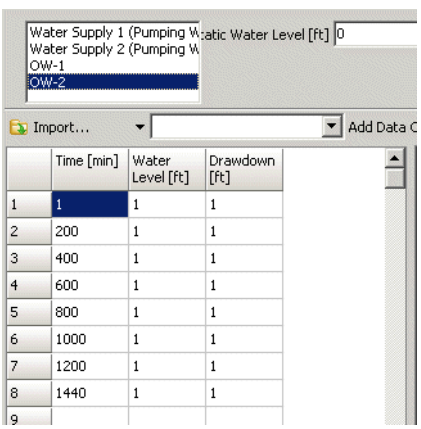
[47] Select the **Water Levels** tab

[48] Select **OW-2** from the list of wells.

Enter the following "dummy" data points for this well.

Time	Water Level
1	**1**
200	**1**
400	**1**
600	**1**
800	**1**
1000	**1**
1200	**1**
1440	**1**

[49] Enter the **Depth to static water level** of 0.



NOTE: These values are dummy points. They are used to establish the time period in which you are interested - the water level values are irrelevant since you are going to PREDICT them. **AquiferTest** simply requires Water Level data to accompany the Time intervals.

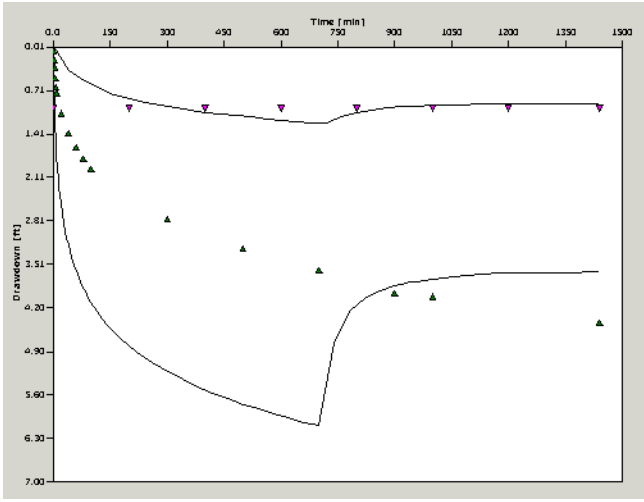
[50] Click on the (Refresh) button in the toolbar, to refresh the graph.

[51] Return to the **Analysis** tab

[52] Check the box beside "**OW-2**"

[53] Click on the

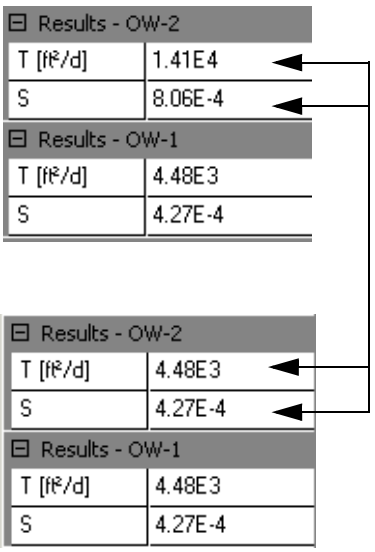
(Automatic Fit) icon, to fit the data to the type curve.



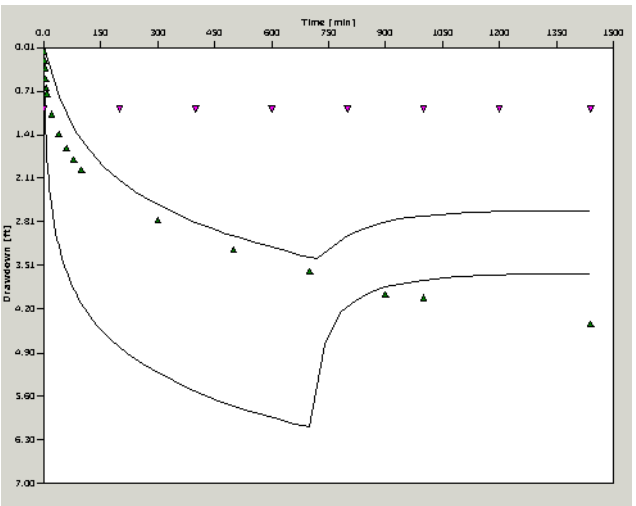
The calculated values for the Transmissivity and Storativity for "OW-2" are different from those for "OW-1", since the automatic fit attempted to fit the curve to the dummy values you entered for the drawdown. To calculate the predictive drawdown curve, you must change the Transmissivity and Storativity values for "OW-2" to match those of "OW-1". You will assume that the aquifer parameters at OW1 are the same as those at OW2.

Match your **Results** panel as shown below.

.



[54] Click anywhere on the **Results** navigation panel to apply the changes. The following graph is produced:



The upper curve is the predicted drawdown in the well at the new coordinates.

The actual data points for OW-2 have no bearing on the new drawdowns curve. The curve is the predicted drawdown that would occur, if there were two pumping wells, one running at 150 US gal/min for 24 hours, and another with the same pumping rate, but for only 12 hours. You can see that the drawdown at OW-2 is less than that observed at OW-1. This occurs because OW-2 is located further away from the pumping wells, so the effect is not as pronounced.

[55] Print the desired reports by selecting the **Reports** tab and checking the boxes

beside the reports you wish to print.

[56] Click on the (Print) button in the tool bar, or select **File/Print** from the main menu.

[57] Save your project by clicking on the (Save) icon or selecting **File/Save as** from the main menu.

This concludes the exercise. The next exercise deals with using data corrections - a new feature of **AquiferTest**. You have a choice of exiting the program, or to proceed to the next exercise.

7.5 Exercise 5: Adding Data Trend Correction

This exercise demonstrates the Data Trend Correction feature in **AquiferTest**. The **AquiferTest** project for this exercise is already created; the exercise deals specifically with the aspect of adding a data trend correction to the drawdown values. For more information on the trend correction, please see Chapter 5: Data Pre-Processing.

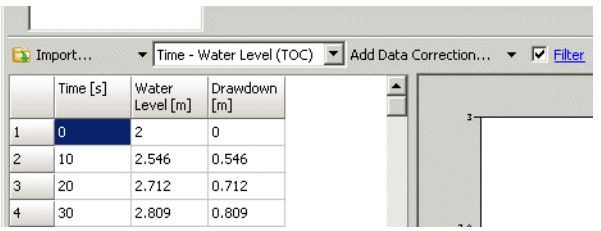
[1] Start **AquiferTest**, and select **File / Open** from the main menu, or click on the **(Open)** button in the tool bar.

[2] Browse to the folder AquiferTest\Examples, and select the project: **TrendEffects.hyt**

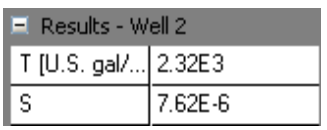
[3] Click **[Open].**

The pumping test consists of one fully penetrating pumping well, pumping at 0.001 m3/s for 30,000 s. Drawdown is observed at an observation well located 10 meters away.

[4] Select the **Water Levels** tab. Take a moment to review the time - drawdown data for **Well 2** that was observed for this pumping test.

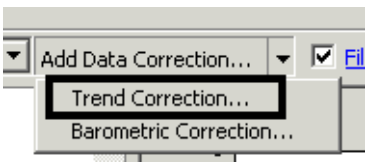


[5] Select the **Analysis** tab. Make note of the results obtained for Transmissivity and Storativity, using Theis analysis.

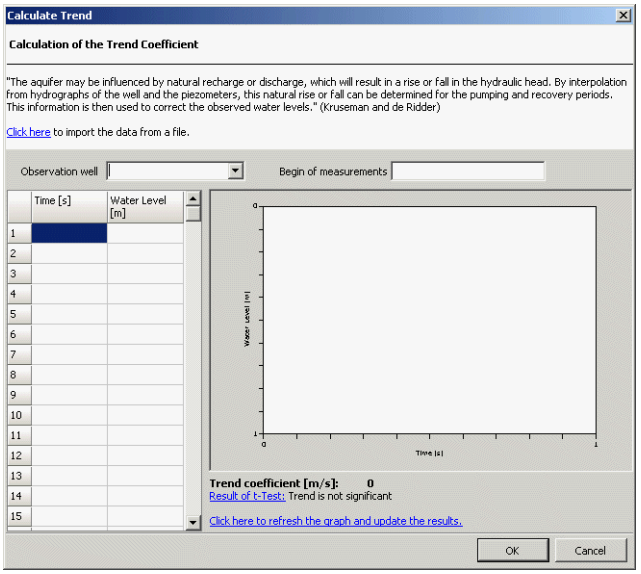


You will now add the trend correction to the observed drawdown measurements.

[6] Return to the **Water Levels** tab. Add a **Data correction**, by clicking on the "down" arrow beside the **Add data correction** button, and selecting **Trend Correction**.



The **Calculate Trend** dialogue will appear

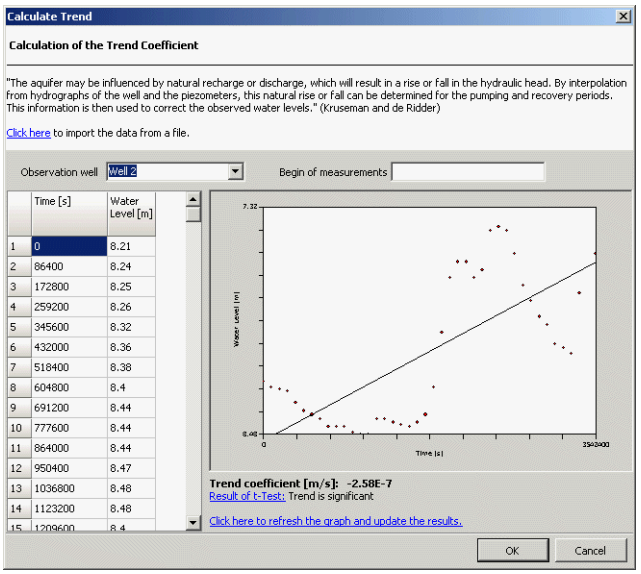

Calculate Trend
Calculation of the Trend Coefficient
"The aquifer may be influenced by natural recharge or discharge, which will result in a rise or fall in the hydraulic head. By interpolation from hydrographs of the well and the piezometers, this natural rise or fall can be determined for the pumping and recovery periods. This information is then used to correct the observed water levels." (Kruseman and de Ridder)
Click here to import the data from a file.
Observation well
Begin of measurements
Time [s]
Water Level [m]
Trend coefficient [m/s]: 0
Result of t-Test: Trend is not significant
Click here to refresh the graph and update the results.
OK
Cancel

[7] In the **Observation well** drop-down menu, select **Well 2** (your observation well)

[8] Follow the **Click here** link above the data table.

[9] Browse to the folder AquiferTest\ImportFiles and locate the file **Trenddata.xls**. This file contains daily measurements of time (s) vs. water level (m) data, recorded by a logger, for 42 days.

[10] Click **[Open]**. You will see the data points displayed in the table and the calculated trend line appear on a graph to the right of the table.


Calculate Trend
Calculation of the Trend Coefficient
"The aquifer may be influenced by natural recharge or discharge, which will result in a rise or fall in the hydraulic head. By interpolation from hydrographs of the well and the piezometers, this natural rise or fall can be determined for the pumping and recovery periods. This information is then used to correct the observed water levels." (Kruseman and de Ridder)
Click here to import the data from a file.
Observation well
Well 2
Begin of measurements
Time [s]
Water Level [m]
1 0 8.21
2 86400 8.24
3 172800 8.25
4 259200 8.26
5 345600 8.32
6 432000 8.36
7 518400 8.38
8 604800 8.4
9 691200 8.44
10 777600 8.44
11 864000 8.44
12 950400 8.47
13 1036800 8.48
14 1123200 8.48
Trend coefficient [m/s]: -2.58E-7
Result of t-Test: Trend is significant
Click here to refresh the graph and update the results.
OK
Cancel

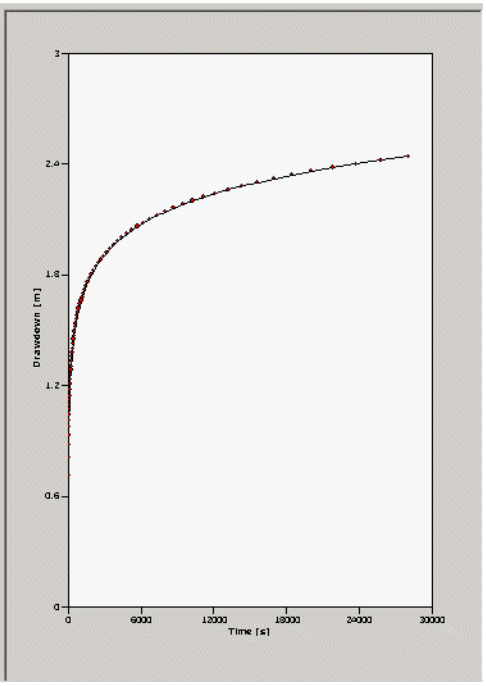
Below the graph you will see the calculated **Trend coefficient** displayed. (If this is not visible, click on the **Click here to refresh the graph and update the results** link below the graph).

At the bottom of the dialog, there will be a label indicating if the trend is significant, which is determined by t-test. In this example, the calculated trend coefficient is -2.58 E-7 m/s (or -2.22 cm/day). The negative sign indicates that the water levels tend to RISE by 2.22 cm/day. The trend is significant; as such, the drawdown values should be corrected with the trend coefficient.

[11] Click **[OK]** to close the dialog.

[12] The correction data has been imported and the **Time/Water Level** table now has two new columns - **Trend correction**, and **Corrected drawdown used in analysis.**

	Time [s]	Water Level [m]	Drawdown [m]	Trend Correction [m]	Corrected drawdown used in analysis [m]
1	0	2	0	0	0
2	10	2.546	0.546	0	0.546
3	20	2.712	0.712	0	0.712
4	30	2.809	0.809	0	0.809
5	40	2.877	0.877	0.0000	0.877
6	50	2.931	0.931	0.0000	0.931
7	60	2.974	0.974	0.0000	0.974
8	70	3.011	1.011	0.0000	1.011
9	80	3.043	1.043	0.0000	1.043
10	90	3.071	1.071	0.0000	1.071
11	100	3.096	1.096	0.0000	1.096
12	110	3.119	1.119	0.0000	1.119
13	120	3.14	1.14	0.0000	1.14
14	140	3.176	1.176	0.0000	1.176
15	160	3.208	1.208	0.0000	1.208
16	180	3.236	1.236	0.0000	1.236
17	200	3.262	1.262	0.0001	1.2621
18	220	3.284	1.284	0.0001	1.2841
19	240	3.305	1.305	0.0001	1.3051
20	270	3.333	1.333	0.0001	1.3331
21	300	3.358	1.358	0.0001	1.3581



Corrected drawdown is calculated using the trend coefficient. To obtain the corrected drawdown, the **Trend Correction** value is added to the observed drawdown. In this example, the **Corrected Drawdown** is slightly greater than the observed drawdown.

[13] Switch to the **Analysis** tab.

[14] Click on the

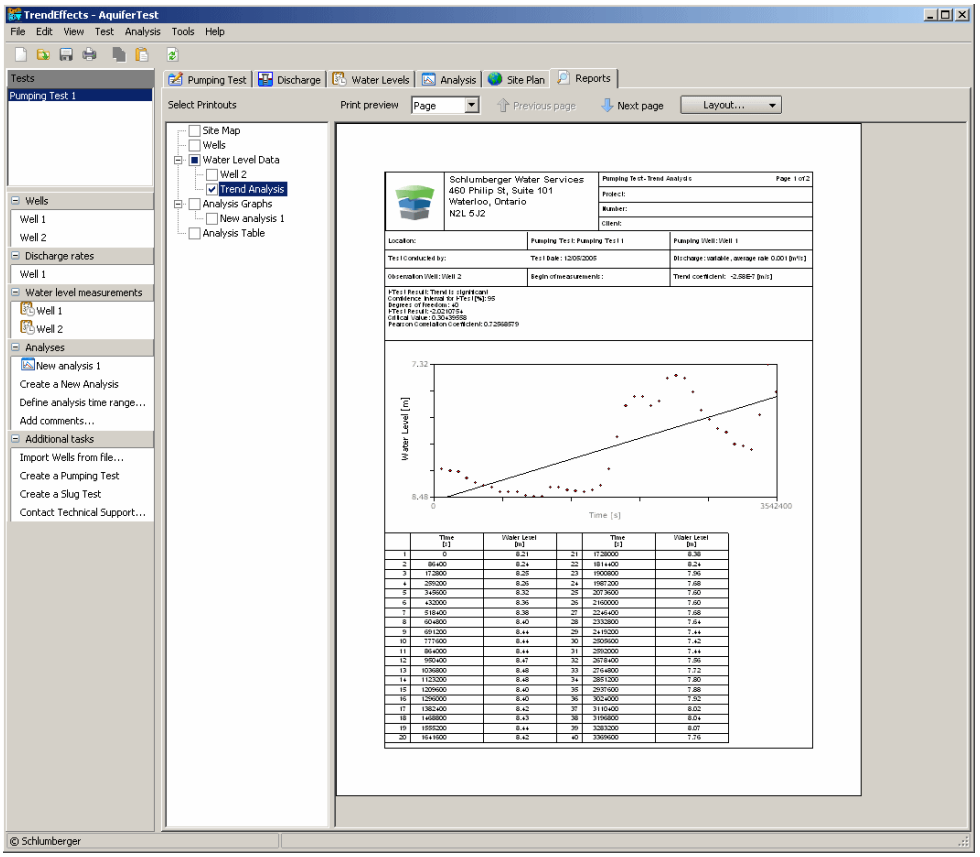
(Automatic Fit) icon, to fit the data to the type curve.

Take note of the new aquifer parameter values. In this example, the values are

unchanged, since the change in drawdown due to the trend is very slight.

Results - Well 2	
T [U.S. gal/...	2.30E3
S	8.03E-6

[15] A Trend report may be printed from the Water Level branch of the navigator tree in the **Reports** tab. This report will display the trend data with corresponding graph, and the t-test statistics. An example is shown below.



This completes the exercise. You may now exit **AquiferTest** or proceed to the barometric correction exercise.

7.6 Exercise 6: Adding Barometric Correction

This exercise will demonstrate how to add a barometric correction to the observed drawdown data. As with the previous exercise, the **AquiferTest** project has already been created for you. The exercise assumes that you are familiar with the **AquiferTest** interface. If not, please review Exercise 1.

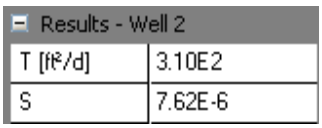
[1] Start **AquiferTest**, and select **File / Open** from the main menu, or click on the (**Open)** button in the tool bar.

[2] Browse to the folder AquiferTest\Examples, and select the project: **Barometric.hyt**

[3] Click **[Open]**

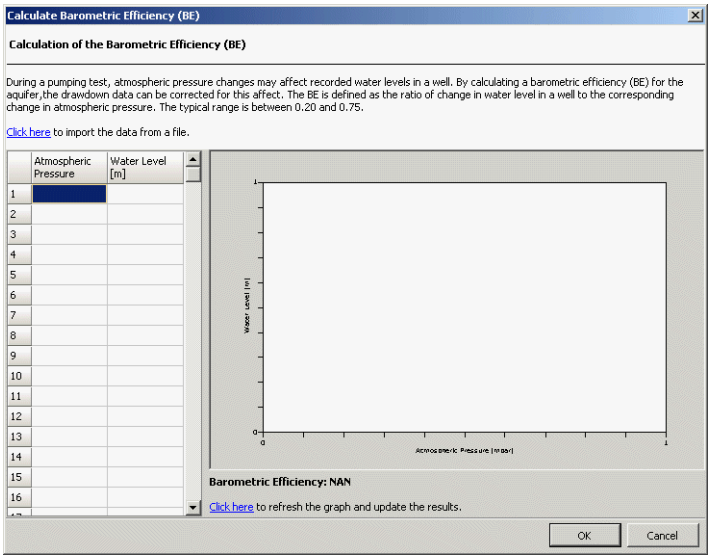
The pumping test consists of one fully penetrating pumping well, pumping at 0.001 m3/s for 30.000 s. Drawdown is observed at an observation well located 10 meters away.

[4] Once the project has loaded, go to the **Analysis** tab and take note of the Transmissivity and Storativity values in the **Results** frame of the **Analysis Navigator** panel



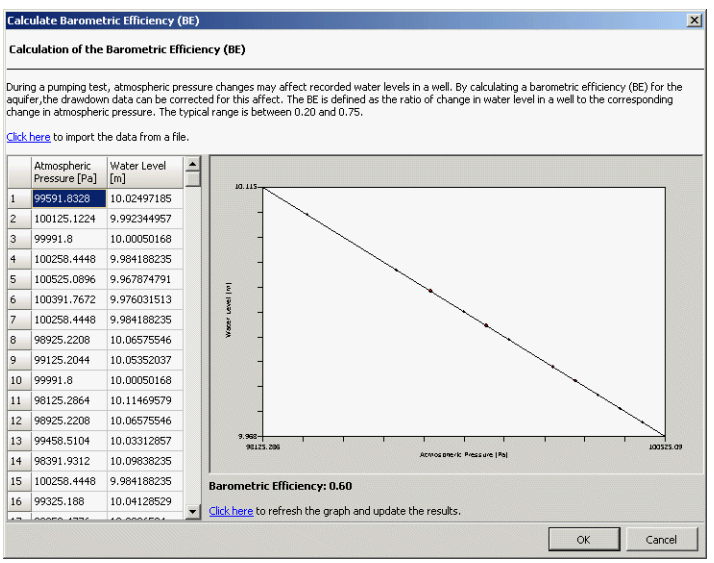
[5] Return to the **Pumping Test** tab and click on the button beside the **Bar. Eff.** field

The following dialog will appear


Calculate Barometric Efficiency (BE)
Calculation of the Barometric Efficiency (BE)
During a pumping test, atmospheric pressure changes may affect recorded water levels in a well. By calculating a barometric efficiency (BE) for the aquifer,the drawdown data can be corrected for this affect. The BE is defined as the ratio of change in water level in a well to the corresponding change in atmospheric pressure. The typical range is between 0.20 and 0.75.
Click here to import the data from a file.
Atmospheric Pressure
Water Level [m]
Barometric Efficiency: NAN
Click here to refresh the graph and update the results.
OK
Cancel

[6] Click on the **Click here** link above the table and browse to the folder AquiferTest\ImportFiles, and locate the file “press-vs-wl.txt” which contains the pressure and water level data. This data was collected before the test.

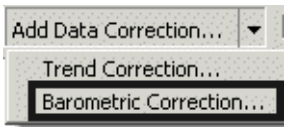
[7] Click **[Open]** to import the file


Calculate Barometric Efficiency (BE)
Calculation of the Barometric Efficiency (BE)
During a pumping test, atmospheric pressure changes may affect recorded water levels in a well. By calculating a barometric efficiency (BE) for the aquifer,the drawdown data can be corrected for this affect. The BE is defined as the ratio of change in water level in a well to the corresponding change in atmospheric pressure. The typical range is between 0.20 and 0.75.
Click here to import the data from a file.
Atmospheric Pressure [Pa]
Water Level [m]
1 99591.8328 10.02497185
2 100125.1224 9.992344957
3 99991.8 10.00050168
4 100258.4448 9.984188235
5 100525.0896 9.967874791
6 100391.7672 9.976031513
7 100258.4448 9.984188235
8 98925.2208 10.06575546
9 99125.2044 10.05352037
10 99991.8 10.00050168
11 98125.2864 10.11469579
12 98925.2208 10.06575546
13 99458.5104 10.03312857
14 98391.9312 10.09838235
15 100258.4448 9.984188235
16 99325.188 10.04128529
Barometric Efficiency: 0.60
Click here to refresh the graph and update the results.
OK
Cancel

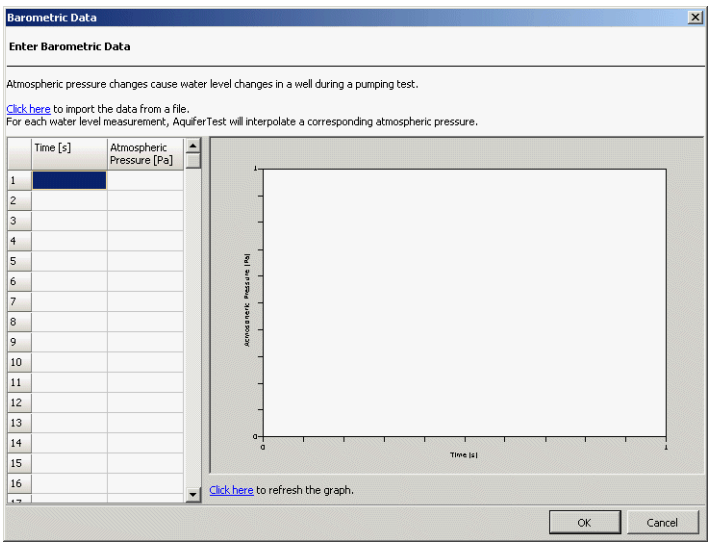
As the data loads into the table, the graph appears to the right of the table and barometric efficiency (B.E.) is calculated and displayed below the graph. If this does not occur, click the **Click here** link below the graph to refresh the display. The calculated barometric efficiency is 0.60.

[8] Click **[OK]** to close this dialog, and notice that “0.60” now appears in the **Bar. Eff.** field in the **Aquifer Properties** frame in the Pumping Test tab.

[9] Return to the **Water Levels** tab. Add a **Barometric correction** to **Well 2**, by clicking on the “down” arrow beside the **Add data correction** button, and selecting **Barometric Correction**.

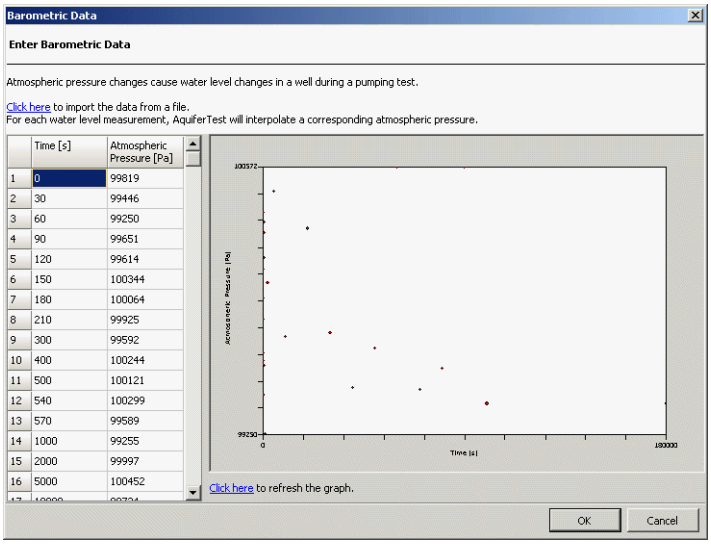


The following dialog will appear

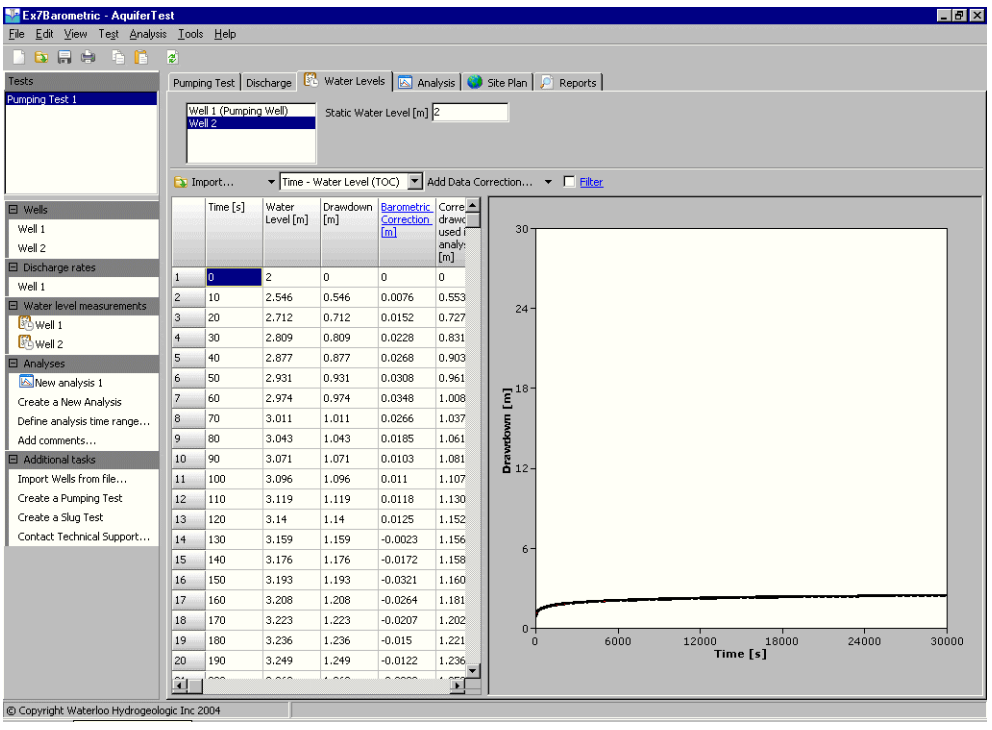

Barometric Data
Enter Barometric Data
Atmospheric pressure changes cause water level changes in a well during a pumping test.
Click here to import the data from a file.
For each water level measurement, AquiferTest will interpolate a corresponding atmospheric pressure.
Time [s]
Atmospheric Pressure [Pa]
Click here to refresh the graph.
OK
Cancel

[10] Click on the **Click here** link above the table and browse to the folder AquiferTest\ImportFiles, and locate the file “time-vs-pressure.txt” which contains the time vs pressure data. This data was collected during the test. The data will load into the table, and plotted on the graph window on the right side of the

window, as shown below.



[11] Click **[OK]** to close the dialog, and apply the correction. Two new columns will appear in the **Water levels** table - **Barometric correction** and **Corrected drawdown used in analysis**. An example is shown below:



(For this example, the original water level is modified to show the trend and barometric effect. The time was simply multiplied by 3.)

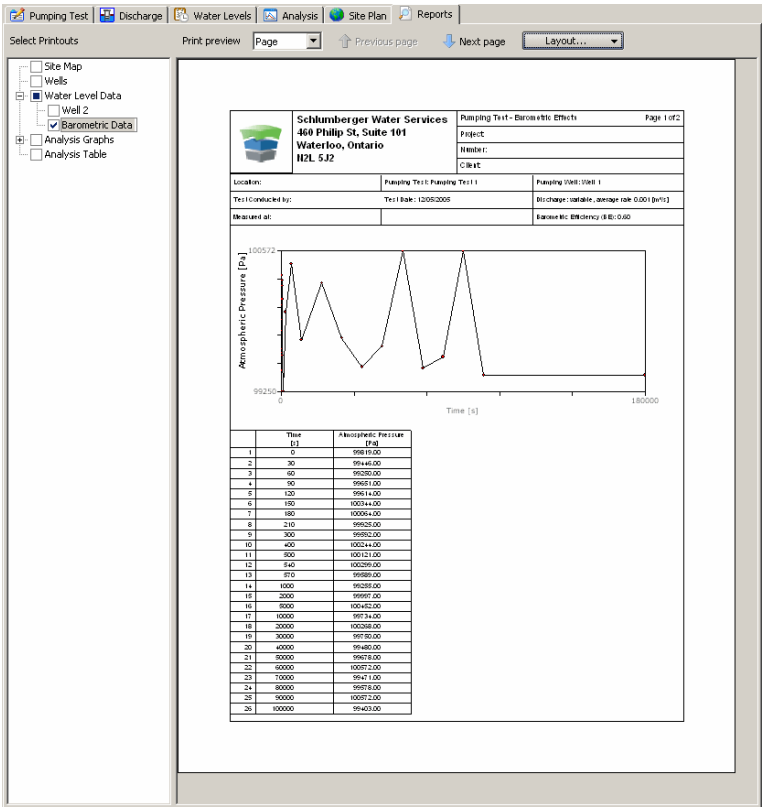
[12] Now, return to the **Analysis** tab.

[13] Click on the

(Automatic Fit) icon, to fit the data to the type curve.

Take note of the new aquifer parameter values.

[14] A Barometric Analysis report may be printed from the Water Level branch of the navigator tree in the **Reports** tab. This report will display the trend data with corresponding graph, and the t-test statistics. An example is shown below



The next exercise will deal with the Hvorslev slug test analysis. You have the choice of exiting **AquiferTest** or continuing on to the next exercise.

7.7 Exercise 7: Slug Test Analysis

This exercise is written with the assumption that you have gone through the first exercise, and are familiar with the **AquiferTest** interface.

This exercise is based on the slug test data published in Fetter, Applied Hydrogeology, 3rd Edition, 1994, p. 250.

[1] Start **AquiferTest,** or if you already have it open, create a new project by clicking the (New) icon in the toolbar or selecting **File/New** from the main menu.

[2] Create a new slug test by selecting **Test/Create a Slug Test** from the main menu.

[3] Complete the fields for the Slug Test as follows:

Project Information frame

- **Project Name:** Exercise 7
- **Project No.:** 7
- **Client:** ABC
- **Location:** Your Town

Slug Test frame

- **Name:** Hvorslev and Bouwer Rice Analysis
- **Performed by:** Your Name
- **Date:** filled in automatically

Units frame

- **Site Plan:** ft
- **Dimensions:** ft
- **Time:** s
- **Transmissivity**: ft^2/d

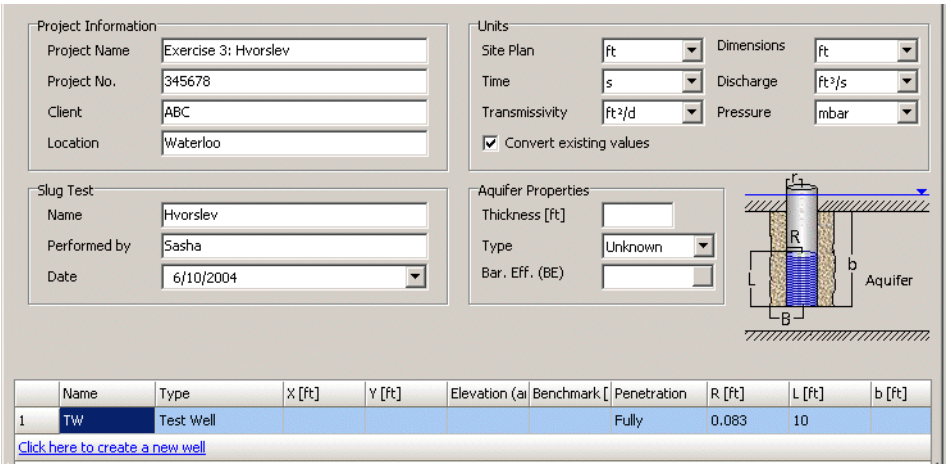
Remaining units are not used, and can be left as is.

[4] In the **Wells** table a well has been created automatically. By default, the type is set to **Not Used**. Change the type to **Test Well** by activating the **Type** cell of the well and then clicking again to produce a drop-down menu (DO NOT double-click).

[5] Enter the following information for the well:

- **Name:** TW
- **R:** 0.083
- **L:** 10

- **r:** 0.083



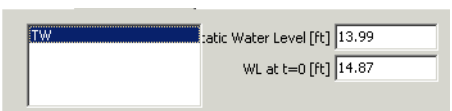
[6] Click on the **Water Levels** tab to enter the water level data for the test well

[7] In this exercise you will enter the data manually. Type in the following information using Tab key or arrow keys to move from cell to cell.

Time	**Water Level**
0	**14.87**
1	**14.59**
2	**14.37**
3	**14.2**
4	**14.11**
5	**14.05**
6	**14.03**
7	**14.01**
8	**14.0**
9	**13.99**

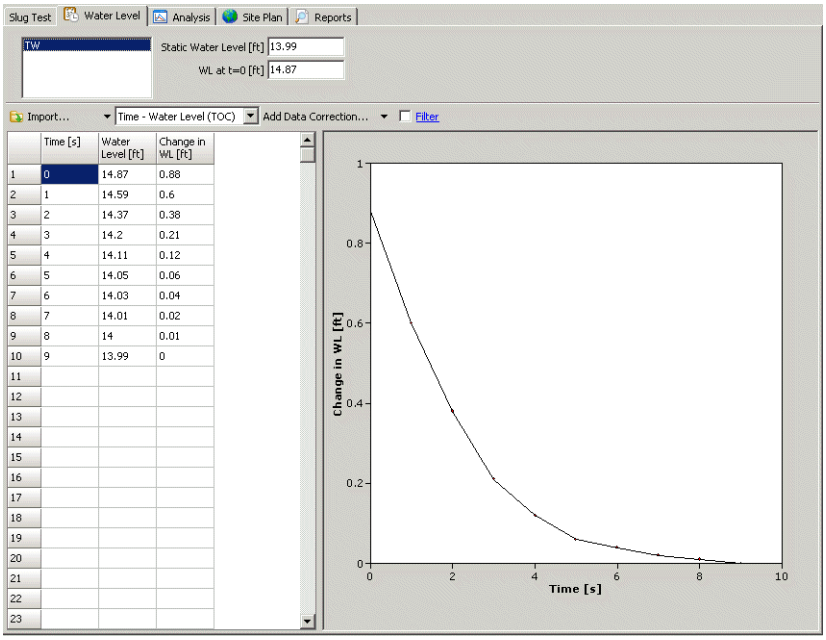
[8] For the **Static Water Level** enter 13.99

[9] For the **Depth at t=0** enter 14.87



[10] Click on the (Refresh) button in the toolbar, to refresh the graph. The calculated drawdown appears in the **Drawdown** column and a graph of the

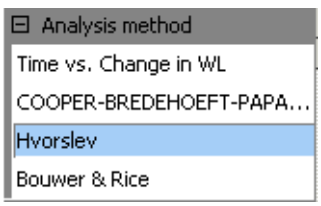
drawdown appears to the right of the data, as shown below.



[11] Click on the **Analysis** tab

[12] In the **Analysis Name** type in “Hvorslev”. Notice that this name now appears in the **Analyses** frame of the **Project Navigator** panel

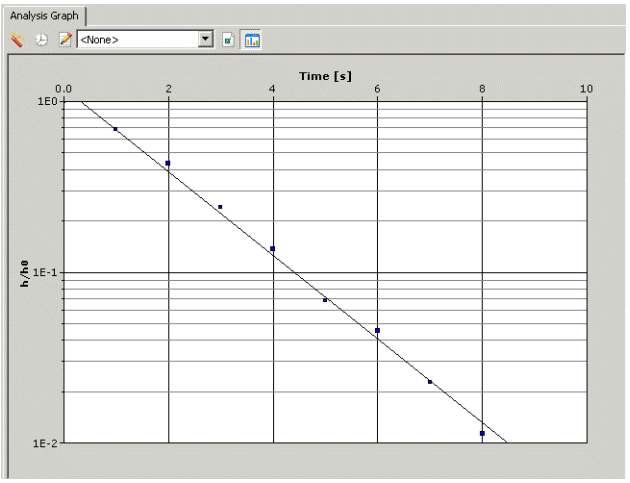
[13] From the **Analysis method** frame of the **Analysis Navigator** panel choose “Hvorslev”



[14] Set the **Max** and **Min** values on both axes so that the graph fits comfortably on the page.

[15] Click on the

(Automatic Fit) icon, to fit the data to the type curve.



[16] If you are not satisfied with the fit of the line, use **Parameter Controls** to adjust it.

[17] Once you are finished, the results in the **Results** frame of the **Analysis Navigator** panel should display the calculated conductivity value:

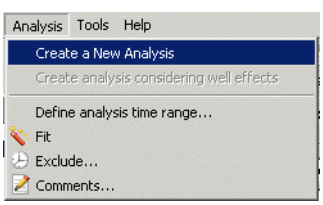
K = 8.10 E+1 ft/d (81 ft /day)

The following table illustrates a comparison of the conductivity value, to that obtained in **AquiferTest 3.5**, and with the published reference.

	AquiferTest 4.X	**AquiferTest 3.5**	**Published (Fetter, 1994)**
Conductivity (ft/d)	8.37 E+1	8.39 E+1	7.9 E+1

[18] For this slug test data, you can also perform the Bouwer & Rice analysis.

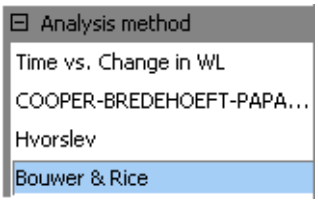
[19] Create a new analysis by selecting **Analysis/Create a new analysis** from the main menu:



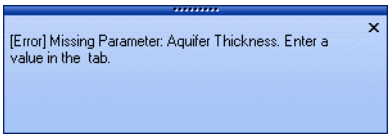
[20] In the **Analysis Name** field, type **Bouwer & Rice**. Notice this name now appears in the **Analyses** frame of the **Project Navigator** panel

[21] Select Bouwer & Rice from the **Analysis Method** of the **Analysis Navigator**

panel



[22] A warning message will appear, indicating “Missing Parameter, Aquifer Thickness”:



[23] Return to the **Slug Test** tab and locate the **Thickness** field in the **Aquifer Properties** frame

[24] Enter a value of **10.0**

[25] Return to the **Analysis** tab

[26] Select “Bouwer & Rice” in the **Analysis** frame of the **Project Navigator** panel

[27] Click on the

(Automatic Fit) icon, to fit the data to the type curve.

[28] If you are not satisfied with the fit of the line, use **Parameter Controls** to adjust it.

[29] Once you are finished, the **Results** frame of the **Analysis Navigator** panel will display the conductivity value:

K = 6.47 E+1 ft/d (64.7 ft/day)

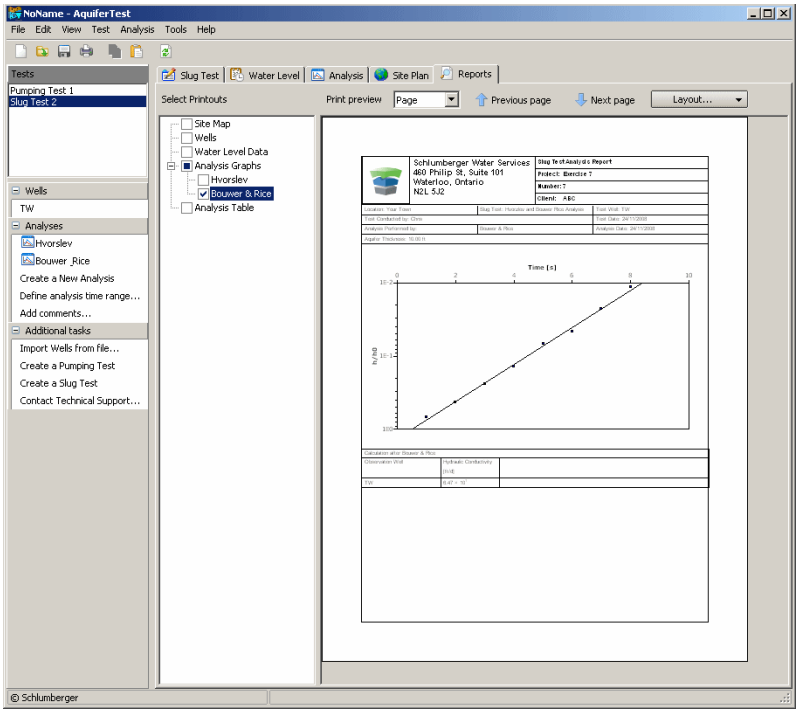
The following table illustrates a comparison of the conductivity value, to that obtained in **AquiferTest 3.5**

	AquiferTest 4.X	**AquiferTest 3.5**
Conductivity (ft/d)	6.47E+1	6.23 E+1

[30] To print your reports go to the **Reports** tab

[31] Expand the navigator tree, and select the box beside “Bouwer & Rice” under **Analysis Graphs**

[32] Check the boxes beside any other reports you wish to print



[33] Click on the **(Print)** button in the tool bar, or select **File/Print** from the main menu.

[34] Save your project by clicking on the (Save) icon or selecting **File/Save as** from the main menu.

This concludes the practice exercises.

If you have any unresolved questions about **AquiferTest**, please feel free to contact us for further information:

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7.8 Additional AquiferTest Examples

Once you have completed the exercises, feel free to explore the sample projects that have been included in the **Examples** folder. These examples encompass a wide variety of aquifer conditions, and appropriate solutions. The following examples are available:

- Agarwal-recovery.HYT: Confined Aquifer, Agarwal recover
- Confined.HYT: Confined Aquifer, Theis Analysis
- Leaky.HYT: Leaky Aquifer, Hantush - Jacob
- Fractured.HYT: Fractured Aquifer, Warren Root Double Porosity
- MultiplePumpingWells.HYT: Confined Aquifer, Multiple Wells
- SpecificCapacity.HYT: Discharge vs. Drawdown, Single Well analysis
- WellBoreStorage.HYT: Well Bore Storage, Papadopulos - Cooper
- PartialPenetration.HYT: Partially Penetrating Wells, Neuman
- Unconfined.HYT: Unconfined Aquifer, Theis with Jacob correction
- SlugTest1.HYT: Bouwer & Rice, Hvorslev
- SlugTest2.HYT: Bouwer & Rice, Hvorslev
- StepTest.HYT: Variable Rate Pumping Test, Theis
- CooperJacob.HYT: Confined Aquifer, Theis Analysis, but using a straight-line method (similar to a Cooper Jacob analysis)
- Moench Fracture Skin.HYT: Fracture flow, fully penetrating wells
- Hantush Bierschenk.HYT: Hantush Bierschenk Well Loss solution
- Hantush Storage.HYT: Leaky Aquifer, Hantush with storage method

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